DANI LUKMAN HAKIM

ENCYCLOPEDIA OF WORLD SOILS

BASED ON SOIL TAXONOMY CLASSIFICATION SYSTEM

jejak pustaka

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SECOND EDITION

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PREFACE

Soil is considered by most people as an inanimate object, a substance which human feet rest upon and buildings stand sturdy. Conversely, through a scientific lens, soil is regarded as a living entity capable of evolving through various stages or phases. Various chemical, physical, and biological reactions are the main processes in the stages of soil development over time, resulting in the presence of youthful soils that haven't undergone much development (juvenile soil) and mature soils that have experienced advanced weathering (senile soil). The dynamic, complex, and continuous system occurring within the soil under specific climate and environmental conditions leads to the formation of different soil types in the world.

This book introduces several soil types from around the world along with their descriptions according to the Soil Taxonomy classification system from the United States Department of Agriculture (USDA). Through this book, insights into the processes and characteristics of each soil type, as well as their purposes, will be unveiled. Although the examples presented in this book represent soils developed in subtropical regions (United States), the formation processes, characterization, and values of these soils are synonymous with soils developed in our surroundings.

Heartfelt gratitude goes to Prof. Dr. Paul McDaniel from Idaho University, who provided suggestions to the author to benchmark the webpage titled "The Twelve of Soil Orders" published on the University of Idaho website, enriching this piece of writing.

September, 2023

Author

LIST OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Indonesia is a country with an extensive land area, covering a total of 1,882,103 square kilometers (Puslittan, 2000). This vast land, supported by diverse topography, microclimates, parent materials, vegetation, and varying ages, has resulted in a wide range of soil types. Referring to the Soil Taxonomy classification system which categorizes soils into 12 orders, Indonesia encompasses nearly all of these orders. Only Aridisols and Gelisols are doubted to exist in Indonesia. Aridisols are formed under arid climates, and their existence in regions like East Nusa Tenggara, which has a climate resembling arid conditions, is uncertain. On the other hand, Gelisols form in extremely cold regions (polar), causing them to have permanently frozen horizons (permafrost). Whether such soils also form in the Jayawijaya Mountains, which have perpetual snow, still requires observation in that region.

The ten soil types (orders) found in Indonesia are Alfisols, Andisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols (Puslittan, 2000). The most extensive soils are Inceptisol (38.51%) and Ultisol (24.27%), as reported by Driessen and Soepraptohardjo (1974). Oxisol (7.50%) and Histosol (7.01%) also cover significant areas. Other soils, like Mollisol, account for 4.56% of the land area. Generally formed from limestone parent materials, these soils usually have high pH and cation exchange capacity (≥ 50%). However, these are not typical Mollisol like those formed in temperate regions with grassland vegetation (prairies).

Alfisols and Andisols have nearly the same extent, comprising 2.77% and 2.55%, respectively. Alfisols develop from intermediate and basaltic volcanic parent materials on relatively young but stable surfaces. Meanwhile, Andisol originates from young volcanic parent materials that are andesitic-basaltic. Acidic parent materials for Andisols are uncommon (Hardjowigeno, 2003). Spodosols, formerly known as Podsols, are rare in Indonesia. Found in Kalimantan on sandy parent materials, its coverage encompasses 1.16% of Indonesia's land area. Lastly, Vertisols covers an area of 1.15%. These soils generally form in depression areas with neutral environmental conditions around them.

CHAPTER I
ENTISOLS

Entisols is one of the soil categories in soil taxonomy classification characterized by minimal or absent horizon development. Horizons are the horizontal layers in the soil formed through natural processes over thousands of years. However, Entisols do not have distinct horizon development due to factors such as rapid geological processes or significant topographical changes. This type of soil is often found in newly formed areas like river deposits, steep slopes, or coastal sandy regions. Due to the lack of horizons, the physical and chemical properties in the Entisols profile tend to be homogeneous throughout its depth. Entisol soil fertility tends to be low due to limitations in the accumulation of organic matter and nutrient minerals associated with horizon development.

Entisol soil has significant implications across various aspects. Agriculture on this type of soil requires careful management due to its low fertility and limited water-holding capacity. Entisols are also more susceptible to erosion, which can be exacerbated by human activities or environmental changes. The incompletely developed soil characteristics offer insights into geological processes occurring in specific environments, aiding scientists in understanding land changes and environmental dynamics. The management and protection of Entisols against erosion can be achieved through soil conservation practices, such as cover cropping or erosion control techniques.

In the context of land development, Entisols often serve as the initial stage of ecological succession, potentially developing into more mature and fertile soil types. Despite their limitations, understanding the characteristics and ecological roles of Entisols is crucial for the sustainable management of natural resources and informed decision-making regarding land use.

Essentially, these soils develop from relatively loose parent materials like volcanic sediments, limestone, and metamorphic rocks.

These soils generally lack any genetic horizons except the A horizon. Entisols are soils that do not fit into the classification of the other 11 soil orders. These soils are characterized by differences based on environmental and land-use considerations. While most Entisols are found in steep rocky areas, those formed from river deposition merging with coastal sedimentation create agricultural lands and habitats for millions of people around the world. Equivalents of Entisols in other classification systems include Alluvial, Regosols, and Litosols.

Entisols cover a considerable area, accounting for 16% of the world's land area. In Indonesia, this type of soil is mostly found in Papua (5.6 million ha), Central Kalimantan (1.54 million ha), South Sumatra (1.27 million ha), and East Nusa Tenggara (0.91 million ha).

Entisols are one of the soil types formed from recent deposits that have not undergone distinct horizon development or naturally formed layers. These soils generally have irregular structure and low organic matter content (Lal, 2009). Due to the lack of horizon development, Entisols have low cation exchange capacity (CEC), resulting in limited water-holding capacity and nutrient availability (Santoso & Cholid, 2021). Consequently, Entisols tend to be infertile and unsuitable for crops requiring adequate water and nutrient availability.

To enhance the fertility of Entisols, adding organic matter to the soil has proven effective. Organic matter can increase CEC and water-holding capacity in Entisols (Santoso & Cholid, 2021). Additionally, research indicates that organic matter additions can enhance the soil's organic carbon content, a soil quality indicator (Fajrina *et al.*, 2020). Thus, adding organic matter can help improve the fertility and quality of Entisol soil.

However, it's important to note that improving Entisols fertility involves more than just adding organic matter; other factors like water management and erosion control must also be considered. Proper water management can maintain sufficient water availability for plants, while erosion control can prevent the loss of potentially fertile soil layers (Lal, 2009).

In related research, analyses of Fe- and Al-humus as well as soil organic carbon in Entisols have been conducted. Analysis results show that Fe- and Al-humus as well as soil organic carbon content can vary depending on the type of Entisols and other environmental factors (Fajrina *et al.*, 2020). Therefore, a deeper understanding of Entisol's characteristics and content can aid in developing more effective management strategies to enhance soil fertility.

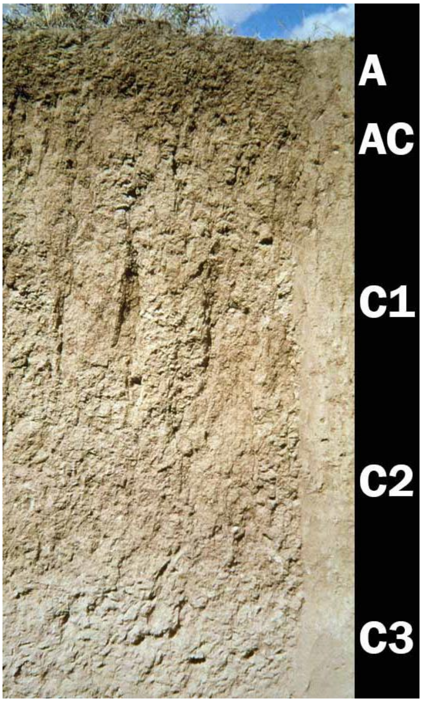


Figure 1. The Profile of Entisols

1.1. ENTISOL SUBORDER CLASSIFICATION

The Entisol Suborder is one of the levels in the taxonomy classification of soils that further details the Entisol soil types. This suborder provides more detailed information about the characteristics and formation conditions of Entisols soils. Several suborders reflect variations in the environment and the processes of Entisols formation.

Entisols are divided into 5 (five) suborders, namely Aquents, Arents, Psamments, Fluvents, and Orthents.

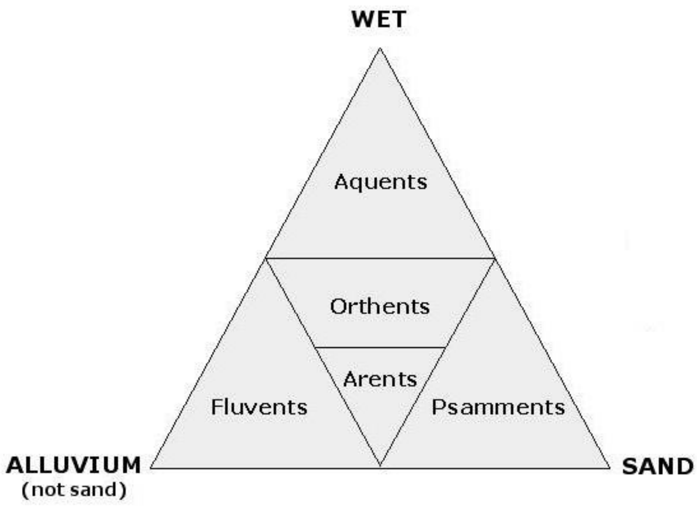


Figure 2. Suborder Diagram of Entisols

Description:

Aquents	-	Entisols with groundwater near the surface almost throughout the year
Arents	-	Disturbed Entisols with diagnostic horizons that are not clearly organized in their differences
Psamments	-	Very Sandy Entisols
Fluvents	-	Alluvial Entisols are typically found in floodplain areas
Orthents	-	Entisols that do not meet the criteria of other suborders

Aquent Suborder

The Aquents suborder is one of the suborders in soil classification that falls under the Entisols group. This suborder pertains to soils whose formation is significantly influenced by water. Aquent soils are often found in areas with shallow groundwater, wetlands, or flood-prone regions that experience rapid changes in water levels. The main characteristic of the Aquent suborder is the significant role of water in the formation of soil layers.

The fluctuating presence of water in the Aquents suborder can lead to the deposition of distinctive mineral and organic materials. During floods or rapid water changes, mineral deposits or organic sediments can be quickly deposited, forming soil layers that differ from other types of Entisols. The changing water conditions also impact plant growth and biological activities within Aquent soils.

Aquent soils have specific properties related to water changes, such as resistance to waterlogging, varying drainage properties, and often high organic content in the upper soil layers. Additionally, due to the fluctuating movement of water, the soil structure in the Aquents suborder might be less well-developed compared to soils that have clearer horizon formation processes.

Understanding the characteristics and conditions of the Aquent suborder is crucial in soil management, especially in areas prone to flooding or rapid water changes. Utilizing such soils for agriculture or other human activities requires special consideration regarding water management, irrigation, and erosion control to ensure sustainable utilization.

Arent Suborder

The Arents suborder is a significant subdivision within the Entisol soil classification, which provides additional insights into the characteristics and formation conditions of specific Entisol soils. This suborder is particularly relevant for soils that have undergone disturbance or human-induced changes, resulting in the presence of diagnostic horizons that are not distinctly organized. The term "Arents" signifies a disruption or alteration of the normal soil development processes.

Arent soils are often characterized by disturbances such as human activities, construction, or other land use changes that have disrupted the natural soil-forming processes. These disturbances can include activities like mining, excavation, or urban development. As a result, Arent soils may exhibit irregularities in their horizon development, making it challenging to identify clear and consistent horizons within the soil profile.

The diagnostic horizons within Arent soils might not follow the typical pattern found in undisturbed soils. Instead, they might show mixed and unstructured layers due to the various materials that have been mixed or disturbed. These diagnostic horizons can provide valuable insights into the history of land use and disturbance in a particular area, serving as indicators of past human activities.

Psamment Suborder

The Psamments suborder is one of the suborders in soil classification that falls under the Entisols group. This suborder refers to soils where the formation is predominantly dominated by sand. Psamment soils are commonly found in areas with a significant presence of sand, such as beaches, sand dunes, or dry climates. The distinctive feature of the Psamments suborder is the dominance of sand particles in the soil structure.

Sand, which is a relatively coarse soil particle, dominates the soil structure in the Psamments suborder. This impacts the physical properties of the soil, such as excellent drainage due to low water retention, but also a lack of capacity to hold nutrients and water. The presence of sand can also result in the absence of well-developed horizons in the soil profile.

Psamment soils often have low organic matter content as sand has a low ability to retain organic materials. However, the dominant sand also contributes to the presence of large pores in the soil, providing good aeration for plant roots. This can enable the growth of plants that are resilient to dry conditions.

Soil management within the Psamments suborder needs to consider the characteristics of sand that dominate the soil structure. Effective agricultural practices on Psamments soils involve wise irrigation techniques, appropriate fertilizer application, and the implementation of soil conservation practices to prevent erosion. The selection of suitable plants to grow in sandy conditions is also crucial for the success of agriculture on Psamment soils.

In natural resource management, understanding the Psamments suborder aids in proper land planning and utilization, especially in areas with significant sand presence. Efforts to maintain ecosystem balance and prevent soil degradation should be considered in the utilization of Psamment soils to ensure sustainability.

Fluvent Suborder

The Fluvents suborder is a distinctive subset within the Entisol soil classification, shedding light on a specific category of soils that have been significantly affected by the deposition and redistribution of alluvial materials. Alluvial deposits are materials like sediment, silt, and clay that are carried and deposited by water, often resulting from flooding events. The term "Fluvents" signifies the fluviatile origin of these soils, emphasizing their formation through the dynamic actions of rivers and watercourses.

Fluvent soils are typically found in floodplains, river valleys, and areas frequently inundated by water. The unique feature of Fluvents suborder soils is their formation through recent alluvial deposition and subsequent redistribution by water movement. The repeated flooding and sediment deposition contribute to the development of unique soil characteristics.

These soils exhibit distinctive features within their profiles, usually characterized by multiple layers of alluvial materials that have been deposited during various flood events. These deposits often lead to the formation of high clay content layers, known as clay skins, which can affect water movement and drainage patterns within the soil. The repeated deposition and movement of materials create a dynamic and ever-changing soil environment.

Fluvent soils play a crucial role in floodplain ecosystems and agriculture. While the repeated deposition of alluvial materials contributes to soil fertility due to the accumulation of nutrients, these soils can also present challenges. The high clay content layers can lead to poor drainage and compaction issues, affecting root growth and water movement. Effective land management practices are essential to ensure that the benefits of these soils are maximized while mitigating potential challenges.

Orthent Suborder

The Orthent suborder is a noteworthy subdivision within the Entisol soil classification, focusing on a specific group of soils that have developed under specific environmental conditions characterized by permafrost. Permafrost refers to soil and rock that remain frozen for extended periods, often occurring in cold climates. The term "Orthents" highlights the frozen nature of these soils and their distinctive properties resulting from permafrost influence.

Orthent soils are primarily found in regions with cold climates, particularly in polar and subpolar regions. The key defining feature of the Orthents suborder is the presence of permafrost, which significantly impacts soil development and properties. The frozen ground restricts the movement of water, affecting drainage patterns and influencing the physical and chemical characteristics of the soil.

Due to the presence of permafrost, the soil horizon development in Orthent soils is limited or disrupted. The lower horizons, usually rich in nutrients and minerals, are often inaccessible due to the frozen ground. The surface horizon, known as the active layer, thaws during the warmer months and supports plant growth. However, the underlying frozen layers can restrict root penetration and the movement of water and nutrients.

Orthent soils are known for their unique features, such as ice wedges, which are polygonal cracks formed by the expansion and contraction of ice within the ground. These features are a result of freeze-thaw cycles and are indicative of the permafrost environment. The presence of ice wedges can create challenges for construction and land use, as they can lead to ground instability.

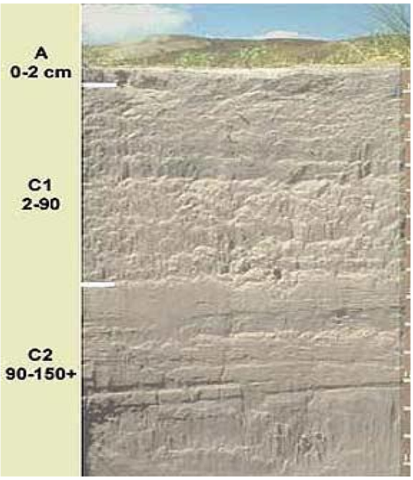
The management of Orthent soils requires a deep understanding of their frozen nature and its implications for land use. In regions with Orthent soils, infrastructure development, agriculture, and resource extraction must consider the presence of permafrost and its effects on soil stability. Innovative approaches, such as building on elevated platforms to avoid disturbing the permafrost, are often employed to mitigate potential negative impacts.

FIGURE 3
THE PSAMMENT SOIL PROFILE AND LANDSCAPE

The Landscape of Torripsamment

This soil is formed in dry areas, generally sandy and very prone to erosion by wind. The photo is set against the backdrop of active sand dunes. The soil exhibits limited development and has a sparse vegetation community. It's also used for irrigated farming and livestock activities; however, water and fertilizer management are crucial. The high natural leaching of this soil makes groundwater vulnerable to contamination, and its natural vegetation can suffer from poisoning.

The Profile of Xeric Torripsamment



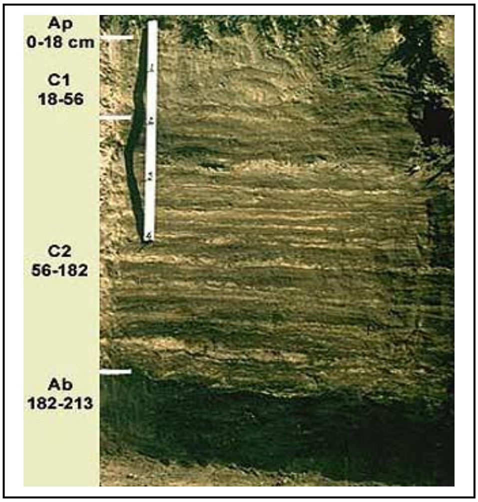
This soil is formed from fine eolian sand. Horizon C2 includes a composition of very fine to fine sand, depicting materials resulting from wind erosion during transport processes. The soil contains little clay and organic matter.

FIGURE 4
THE FLUVENT SOIL PROFILE AND LANDSCAPE

The Landscape of Udifluvent

This aerial photograph depicts the Red River area in Los Angeles, showing the landscape of a typical Fluvent soil. The soil along the riverbank has a dusty texture with the classification of Udifluvent, which is commonly used for agricultural activities. At a greater distance from the riverbank, the soil has a loamy texture and is classified as Vertic Hapludolls. This soil type is typically used for grazing pastures and forests.

The Profile of Typic Udifluvent



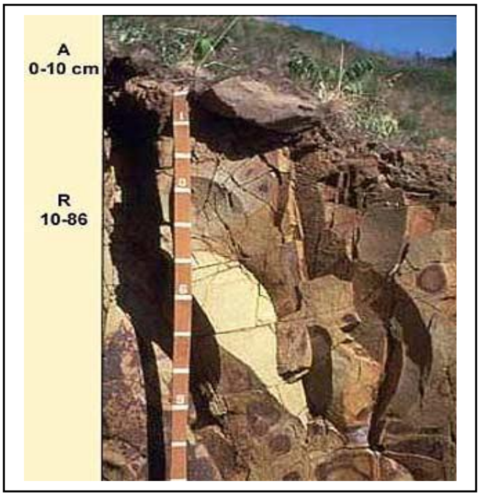
This soil is typically fine-textured with stratified layers of minerals and organic matter. This soil is formed from Alluvial parent material. The dynamic natural conditions in this area have little influence on the horizon development due to the presence of a buried horizon in the soil.

FIGURE 5
THE ORTHENT SOIL PROFILE AND LANDSCAPE

The Landscape of Xerorthent

This type of landscape is known as "patterned ground," resulting from freeze-thaw cycles during the Ice Age when the climate was extremely cold. Xerorthents are found in mossy areas. These soils are very shallow, formed from basaltic rock, and have limited land utility.

The Profile of Lithic Xerorthent



This soil is formed from basaltic residue and is very shallow. Its shallowness severely limits its land use. Most of it is used for grazing land and stone mining.

1.2. THE GLOBAL DISTRIBUTION OF ENTISOLS

Entisols, as a soil order, exhibit a diverse and widespread global distribution. They are found in various climate zones, topographies, and landscapes, making them one of the most common soil orders worldwide. This distribution reflects the processes of soil formation and the different environmental conditions in which Entisols can develop.

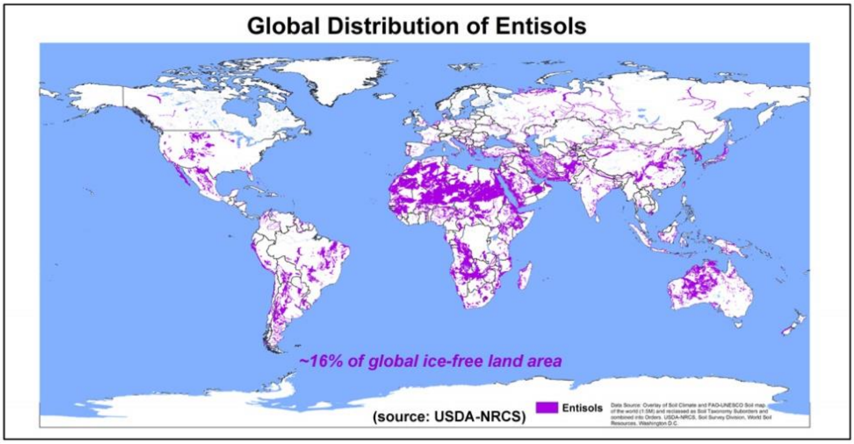


Figure 6. The Global Distribution of Entisols

In temperate regions, Entisols often occur in areas with relatively young and recently deposited materials. These regions include floodplains, river valleys, and areas with steep slopes. The dynamic processes of sediment deposition and erosion contribute to the formation of Entisols in these areas. For instance, in North America, Entisols can be found in parts of the Great Plains, where the relatively recent deposition of materials has led to the development of these soils.

In tropical and subtropical regions, Entisols can be found in a range of landscapes, from coastal areas to hilly terrains. The presence of abundant rainfall and high temperatures accelerates the weathering and erosion processes that contribute to Entisol formation. In countries like Indonesia and Brazil, where these conditions are prevalent, Entisols are found in regions that experience rapid soil turnover due to erosion, sedimentation, and vegetation dynamics.

Arctic and subarctic regions also host Entisols, particularly in areas where permafrost dominates the landscape. The freezing and thawing cycles of permafrost contribute to the formation of these soils. For instance, in northern Canada and parts of Russia, Entisols can be found in areas characterized by frozen ground and limited horizon development due to the influence of permafrost.

In arid and semiarid regions, Entisols can develop in landscapes with sparse vegetation cover and limited soil development. The low rainfall and intense evaporation contribute to the accumulation of salts and minerals in the soil, often leading to the formation of saline and alkaline Entisols. These soils are prevalent in regions such as deserts and steppes, including areas in Australia, the Middle East, and parts of the southwestern United States.

CHAPTER II
INCEPTISOLS

Inceptisols is a soil that shows minimal horizon development. This soil is more developed than Entisol but still lacks distinct characteristics of other soil orders. Inceptisols are widely distributed and occur across a broad range of environmental conditions. This soil type is often found on sloping land, young geomorphic surfaces, and weathering-resistant parent materials. Various land uses can be carried out on Inceptisols. A significant extent of this soil type is found in mountainous areas and used for forestry, recreational activities, and as reservoirs for water storage. In other soil classification systems, Inceptisols correspond to Brown Latosols, Grumusols, Brown Forest Soil, Humic Gley, and Solonetz.

Inceptisols, as a soil order, occupy a significant place in the realm of soil classification due to their transitional nature between less developed Entisols and more mature soil orders. These soils exhibit a moderate level of horizon development, indicating that they have progressed beyond the early stages of soil formation but have not yet developed the distinct characteristics of more advanced soil orders. This unique attribute places Inceptisols in a crucial position within the spectrum of soil development.

The formation of Inceptisols occurs in a variety of environmental conditions, making them widely distributed across the globe. They are commonly found on slopes, young geological surfaces, and areas with parent materials that are moderately resistant to weathering. The transitional nature of Inceptisols allows them to adapt to diverse landscapes and climates, from mountainous terrains to lowland regions, making them versatile soil types.

One of the defining features of Inceptisols is their adaptability to various land uses. Due to their moderate development and transitional characteristics, Inceptisols are suitable for a wide range of activities, from agriculture to forestry and recreational purposes. Their distribution across different elevations also makes them important in terms of water resource management, acting as water storage reservoirs in mountainous regions.

Currently, with the changes in the taxonomic system, the extent of Inceptisols covers 17% of the world's land area, making it the most extensive soil order compared to others. In Indonesia, Inceptisols covers an area of approximately 70.52 million hectares. They are found throughout Indonesia's land, including Papua (15.49 million ha), East Kalimantan (6.12 million ha), Central Kalimantan (4.21 million ha), Maluku (4.0 million ha), and the remaining scattered in various regions with smaller areas.

Inceptisols are a type of soil that is widely distributed and central to agricultural land in Indonesia, covering around 37.5% of the country's land area (Herviyanti, 2023). However, Inceptisols face challenges due to their chemical properties, including low organic carbon and total nitrogen content, as well as slightly acidic pH and low nutrient levels (Herviyanti, 2023). These properties contribute to their classification as less fertile soil (Herviyanti, 2023). Inceptisols are also found in alpine regions, where their abundance may be attributed to slow rates of weathering and horizon formation (Bockheim & Munroe, 2014). It has been suggested that some Inceptisols in alpine karst areas are of eolian origin rather than from in situ weathering (Bockheim & Munroe, 2014).

Restoring soil quality is crucial for mitigating soil degradation and improving the fertility of Inceptisols. This can be achieved through practices such as conservation agriculture, integrated nutrient management, residue mulching, cover cropping, and controlled grazing (Lal, 2015). By adopting these recommended management practices, soil erosion can be minimized, and positive trends in soil organic carbon and nitrogen budgets can be created (Lal, 2015). Additionally, enhancing the activity and species diversity of soil biota, as well as improving structural stability and pore geometry, can contribute to the restoration of soil quality (Lal, 2015).

Inceptisols are part of the larger issue of soil degradation, which is a major constraint to achieving the necessary increase in agricultural production to feed the growing global population (Lal, 2015). Soil degradation is characterized by a decline in soil quality and a decrease in ecosystem goods and services (Lal, 2015). It is caused by processes such as accelerated erosion, depletion of the soil organic carbon pool, loss of biodiversity, loss of soil fertility, elemental imbalance, acidification, and salinization (Lal, 2015). To address this issue, it is essential to implement strategies that aim to produce "more from less" by reducing losses and increasing soil, water, and nutrient use efficiency (Lal, 2015).

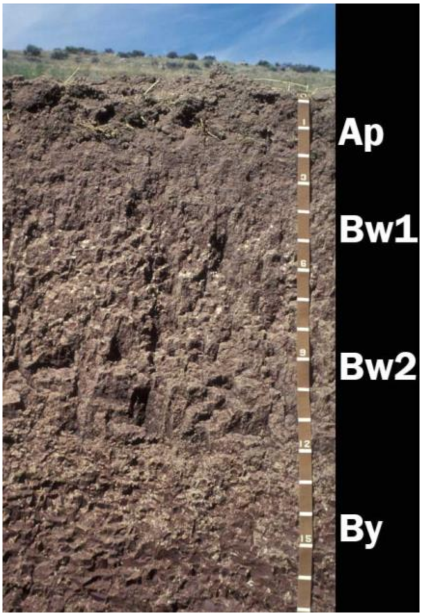


Figure 7. The Profile of Inceptisols

2.1. INCEPTISOL SUBORDER CLASSIFICATION

The suborder classification within Inceptisols provides a finer level of detail and insight into the diversity of these transitional soils. Each suborder represents a distinct set of characteristics, contributing to a comprehensive understanding of Inceptisols' formation and distribution. These suborders take into account variations in climate, parent material, topography, and other environmental factors that influence the development of Inceptisols.

Inceptisols are divided into 7 (seven) suborders, namely Aquepts, Anthrepts, Gelepts, Cryepts, Ustepts, Xerepts, and Udepts.

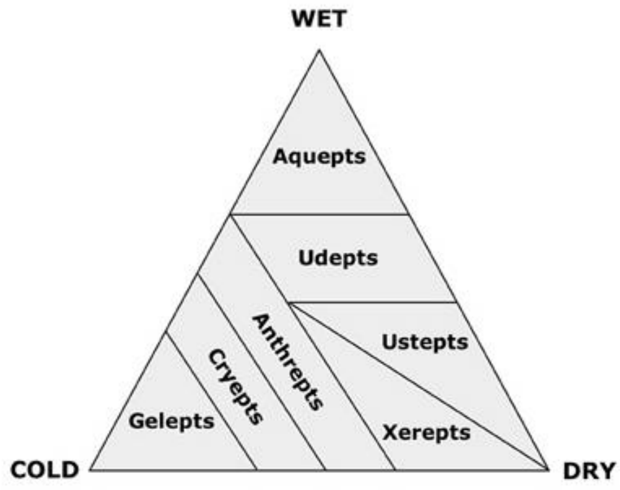


Figure 8. Suborder Diagram of Inceptisols

Description:

Aquepts	-	Inceptisols with groundwater near the surface almost throughout the year
Anthrepts	-	Inceptisols marked by human influence and agricultural activities
Gelepts	-	Inceptisols in extremely cold climates (average annual soil temperature <0°C)
Cryepts	-	Inceptisols in cold climate regions
Ustepts	-	Inceptisols in semi-arid and subhumid climate regions
Xerepts	-	Inceptisols in temperate regions with very dry summers and wet winters
Udepts	-	Inceptisols in humid climate regions

Aquept Suborder

The Aquept suborder is a distinctive category within the classification of Inceptisols that highlights the influence of water dynamics on soil development. Aquepts are characterized by their close association with high water tables, making them well-suited for the study of soils that are significantly influenced by water movements. These soils are typically found in areas with shallow groundwater levels, such as floodplains, riverbanks, and areas near lakes or ponds.

One of the key features of Aquepts is the seasonal or nearly constant presence of high water tables near the soil surface. This consistent water saturation significantly affects the soil's physical and chemical properties, leading to specific horizon development patterns. Aquepts often exhibit well-developed iron and manganese profiles, as the saturated conditions promote the mobilization and accumulation of these elements in distinct soil horizons.

Due to the influence of water, Aquepts may show evidence of gleiing, as a process where iron becomes reduced and imparts characteristic bluish or grayish colors to the soil. These changes in coloration can indicate fluctuating redox conditions caused by water saturation. Additionally, the water-saturated conditions of Aquepts may result in poor natural drainage, which can influence the choice of land use and management practices.

The Aquept suborder has significant implications for land use planning and management. These soils are often fertile and suitable for agricultural activities, particularly rice cultivation and other crops that thrive in wet conditions. However, their waterlogged nature can also pose challenges, such as limited aeration for plant roots and increased vulnerability to erosion when not managed properly. Sustainable land management practices, including appropriate drainage systems, are essential to optimize agricultural productivity while minimizing negative environmental impacts in areas dominated by Aquepts.

Anthrept Suborder

The Anthrept suborder plays a crucial role in the understanding of Inceptisols, focusing on soils that have undergone significant human influence and land use changes. These soils are characterized by the effects of cultivation, plowing, and other human activities that have altered their natural development. The term "Anthrept" itself signifies the anthropogenic impact on the soil profile.

Anthrepts often exhibit changes in horizon development and mineral composition due to human activities. Intense plowing and cultivation can disrupt the natural layering of the soil, leading to the mixing of horizons and the incorporation of organic matter into lower layers. These disturbances can result in the creation of anthropic horizons—layers rich in organic materials, minerals, and artifacts associated with human activities.

The presence of anthropic horizons is a distinctive feature of Anthrepts, indicating the influence of past land use practices. These horizons are often darker in color due to increased organic matter content, and they may contain artifacts such as charcoal, pottery, or other remnants of human activity. The extent and characteristics of these anthropic horizons provide insights into the history of land use and management in the region.

Anthrepts hold significance for both archaeological and agricultural purposes. From an archaeological perspective, the presence of anthropic horizons provides valuable information about past human settlements and activities. From an agricultural standpoint, understanding the alterations caused by human practices is crucial for effective land management. Farmers must consider the implications of previous cultivation and plowing when planning current agricultural practices, irrigation systems, and erosion control measures.

Gelept Suborder

The Gelept suborder is a distinctive classification within the realm of Inceptisols, focusing on soils that have developed under the influence of permafrost conditions. These soils are found in cold regions where the presence of permafrost, a layer of permanently frozen ground plays a significant role in shaping their properties. The term "Gelept" highlights the presence of permafrost and its impact on soil development.

One of the defining characteristics of Gelepts is the presence of permafrost within the soil profile. This permafrost layer can be found at varying depths below the soil surface and is responsible for influencing soil properties, drainage patterns, and nutrient cycling. The freeze-thaw cycles associated with permafrost can lead to the formation of distinctive soil horizons and patterns of soil movement.

The freeze-thaw cycles of permafrost can lead to the development of cryoturbation, a process where the movement of soil particles due to freezing and thawing creates irregular soil horizons. These horizons are often referred to as cryogenic horizons and are a hallmark of Gelept soils. The combination of these cryogenic horizons and the unique mineralogy influenced by permafrost conditions distinguishes Gelepts from other Inceptisols.

Gelept soils have important implications for land use and environmental management. The presence of permafrost can influence soil drainage, affecting the availability of water to plants and other soil organisms. Additionally, the freeze-thaw processes associated with permafrost can lead to soil heaving, which can impact construction and infrastructure development. As permafrost conditions change due to climate change, the properties and distribution of Gelept soils may also be influenced.

Cryept Suborder

The Cryept suborder is a significant classification within the Inceptisols group, focusing on soils that exhibit cryoturbation—a distinctive process caused by the freeze-thaw cycles of permafrost in cold environments. These soils are found in regions where permafrost conditions influence their development, resulting in unique soil characteristics and properties. The term "Cryept" underscores the role of cryoturbation in shaping these soils.

One of the defining features of Cryept soils is the presence of cryoturbation, which refers to the mixing and movement of soil particles due to the expansion and contraction caused by repeated freezing and thawing. This process results in the formation of irregular soil horizons and patterns known as cryogenic features. These features are characterized by the movement of soil materials, leading to a unique vertical arrangement of soil particles and the creation of distinct soil layers.

Cryept soils often have cryogenic horizons that are indicative of the repeated cycles of freezing and thawing. These horizons can be identified by their altered mineralogy, structure, and arrangement of soil particles. The extent and intensity of cryoturbation can vary, resulting in a range of cryogenic features within Cryept soils. These distinctive characteristics provide insights into the history of freeze-thaw cycles and permafrost conditions in the region.

The presence of cryogenic features in Cryept soils has implications for soil properties, drainage, and land use. Cryoturbation can affect soil structure and permeability, influencing water movement and drainage patterns. Additionally, the mixing of soil materials can impact nutrient distribution and availability to plants and other soil organisms. Understanding these soil properties is crucial for making informed decisions about land use, agricultural practices, and environmental management in cold regions.

Ustept Suborder

The Ustept suborder is a significant classification within the Inceptisols group, focusing on soils that have experienced significant moisture and temperature fluctuations due to seasonal changes. These soils are found in temperate regions where distinct seasons, characterized by warm summers and cold winters, play a significant role in shaping soil properties. The term "Ustept" highlights the pronounced seasonal variability that impacts these soils.

One of the defining characteristics of Ustept soils is the presence of seasonal fluctuations in temperature and moisture. These fluctuations result in a process known as cryoturbation, where the expansion and contraction of soil particles due to freeze-thaw cycles lead to the mixing and movement of materials. This process creates distinctive horizons and patterns, contributing to the unique properties of Ustept soils.

Ustept soils typically exhibit evidence of cryoturbation in the form of cryogenic features—irregular soil horizons and patterns caused by freeze-thaw cycles. These features are particularly pronounced in regions with well-defined seasons and significant temperature variations. The influence of cryoturbation affects soil structure, mineralogy, and the distribution of organic materials, ultimately shaping the development of Ustept soils.

The seasonally variable nature of Ustept soils has important implications for their use and management. These soils often exhibit improved drainage during the warmer months but can become waterlogged during the wetter seasons. This variability in soil moisture can influence plant growth, nutrient cycling, and other soil-related processes. Understanding the seasonal dynamics of Ustept soils is crucial for effective land management, especially in agricultural contexts.

Ustept soils play a vital role in temperate ecosystems, affecting vegetation composition and water availability. These soils can support a variety of plant species adapted to the seasonal moisture and temperature fluctuations. Additionally, the distinctive features of Ustept soils, resulting from cryoturbation and seasonal processes, contribute to the overall diversity of soil landscapes and provide valuable insights into the complex interactions between climate, vegetation, and soil development.

Xerept Suborder

The Xerept suborder is a significant classification within the Inceptisols group, focusing on soils that have developed under arid or semi-arid climatic conditions. These soils are found in regions characterized by limited rainfall and high evaporation rates, where water availability is a critical factor influencing soil formation and properties. The term "Xerept" highlights the arid conditions that shape the development of these soils.

One of the defining features of Xerept soils is their adaptation to arid environments. These soils often have unique properties and horizons that reflect their response to water scarcity. Xerept soils can exhibit features such as calcic or petrocalcic horizons, which form due to the accumulation of calcium carbonate as a result of limited leaching and high evaporation rates.

Xerept soils are well-suited to environments where water availability is limited, and plants must adapt to survive in arid conditions. These soils often have distinct plant communities that are adapted to the low water availability and high mineral content of Xerept soils. The presence of calcium carbonate can influence soil pH and nutrient availability, affecting the types of vegetation that can thrive in these environments.

Due to their unique characteristics, Xerept soils have implications for land use and management. The limited water-holding capacity of these soils can influence agricultural practices, requiring careful irrigation strategies and selection of drought-resistant crops. Additionally, the presence of calcic or petrocalcic horizons can impact soil structure and permeability, influencing water movement and drainage patterns.

Xerept soils play a crucial role in arid and semi-arid ecosystems, contributing to the diversity of soil landscapes and supporting specialized plant communities. These soils provide insights into the interactions between climate, water availability, and soil properties. Understanding the formation and properties of Xerept soils is essential for sustainable land management and conservation efforts in arid regions.

Udept Suborder

The Udept suborder is a significant classification within the Inceptisols group, encompassing soils that have formed under wet conditions with pronounced drainage patterns. These soils are typically found in regions where high levels of precipitation and moisture contribute to their distinctive properties. The term "Udept" highlights the importance of wetness and drainage in shaping the development of these soils.

One of the defining features of Udept soils is their strong drainage characteristics. These soils have well-defined horizons that result from leaching and downward movement of water through the soil profile. Udept soils often exhibit the presence of an argillic horizon, which forms due to the accumulation of clay and minerals that have migrated downward through the soil.

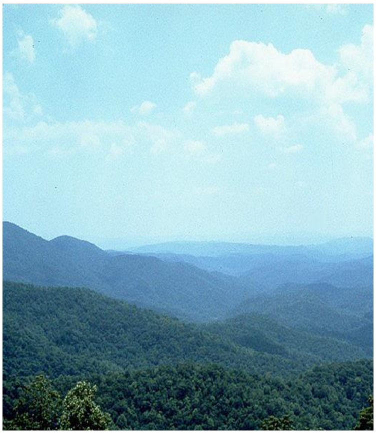
Udept soils are particularly well-suited to areas with abundant rainfall and high moisture content. The frequent wetting and drying cycles can influence soil structure, mineral distribution, and the availability of nutrients. These soils often support diverse plant communities adapted to the wet conditions, and their ability to retain moisture can contribute to the growth of vegetation.

Due to their distinctive drainage properties, Udept soils have important implications for land use and management. These soils can be suitable for various agricultural activities, but proper drainage management is essential to prevent waterlogging and ensure optimal conditions for plant growth. Additionally, the leaching process in Udept soils can lead to the loss of nutrients, requiring careful consideration of fertilization practices.

Udept soils play a crucial role in supporting wetland ecosystems and influencing hydrological processes. These soils contribute to water retention, groundwater recharge, and flood regulation. The presence of Udept soils in wetland areas helps to maintain water quality and support habitats for diverse plant and animal species.

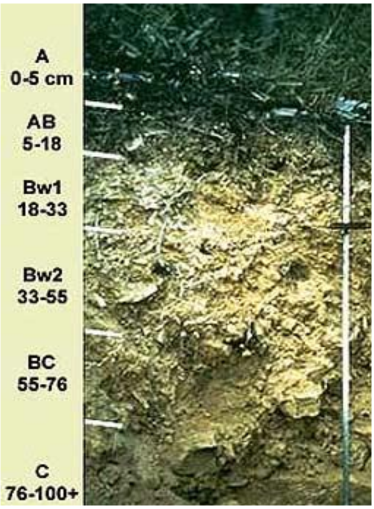
FIGURE 9
THE UDEPT SOIL PROFILE AND LANDSCAPE

The Landscape of Dystrudept



Dystrudept typically forms on sloping land in wet (humid) climatic regions. This Appalachian landscape represents hardwood forests, illustrating the land use type on this soil. Dystrudept is formed from the weathering of sandy rock and shale rock residues and is usually rocky with shallow depth.

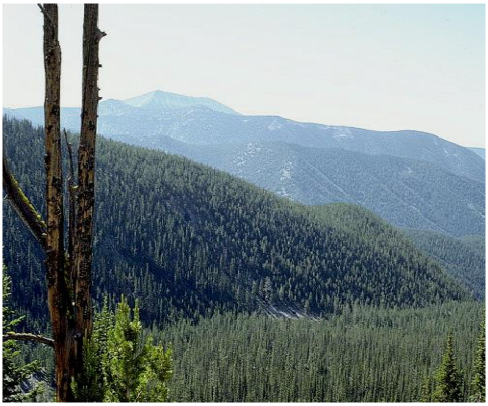
The Profile of Typic Dystrudept



This soil is formed on colluvium originating from acidic sandstone. Dystrudept often forms with weak consolidation levels with acidic parent material from sedimentary and metamorphic rocks. As a result, base saturation and soil pH are relatively low. This soil has an ochric epipedon, an epipedon above the cambic Bw horizon, with good drainage conditions and usually occurs on sloping land.

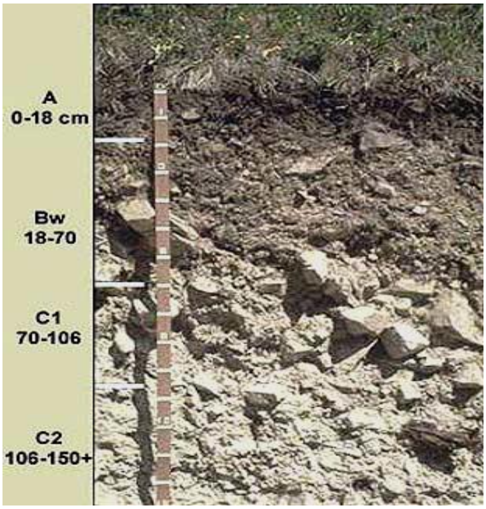
FIGURE 10
THE CRYEPT SOIL PROFILE AND LANDSCAPE

Landscape of Dystrocryept



Soil formed on this landscape is usually thin and develops weakly with a high percentage of rock fragments. These characteristics result in a low water-holding capacity. The low water-holding capacity and the limited amount of rainfall during the summer lead to low wood production on this soil. The primary use of this soil is for nature reserves and extensive recreational facilities, such as open natural recreation. This landscape is an important water reserve for irrigation and a source of livelihood downstream.

The Profile of Xeric Dystrocryept



This soil is found in steep mountainous areas in eastern Central Idaho. This soil is formed on colluvium originating from quartzite, resulting in low base saturation and acidic pH. The steep slope and cold climate contribute to the slow development of this soil.

2.2. THE GLOBAL DISTRIBUTION OF INCEPTISOLS

Inceptisols, a soil order within the Soil Taxonomy classification, are distributed across various regions around the world, reflecting their versatility and adaptability to different environmental conditions. These soils occupy a significant portion of the Earth's land area and are found in a wide range of climates and landscapes. Their presence is particularly notable in areas with relatively young and active geological processes.

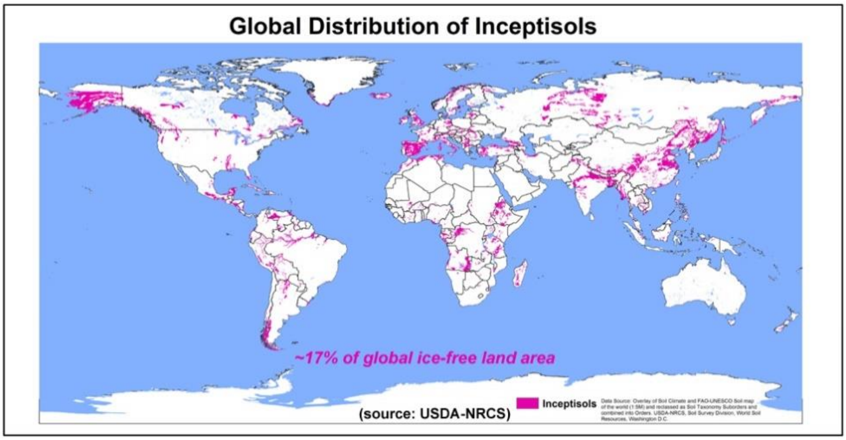


Figure 11. The Global Distribution of Inceptisols

Inceptisols are frequently encountered in regions characterized by dynamic landforms such as young terrains, hillslopes, and floodplains. They can be found in both temperate and tropical climates, adapting to different temperature and moisture regimes. In tropical regions, Inceptisols are often associated with areas where rapid weathering and leaching processes occur due to high rainfall. Conversely, in drier climates, they are often linked to areas with sporadic moisture availability, giving rise to distinct soil profiles.

These soils are commonly found in areas with variable topography, ranging from hilly to gently rolling landscapes. Slope gradients influence the degree of soil development and profile differentiation within Inceptisols. Steeper slopes may hinder the formation of well-defined horizons, while gentler slopes could facilitate more pronounced soil horizons. Therefore, the global distribution of Inceptisols is strongly linked to factors such as topography, climate, and parent material.

Inceptisols's adaptability and widespread distribution make them important in various land uses. They are often utilized for agriculture, as they can be suitable for cultivating a range of crops when managed properly. However, their diverse distribution also implies that their agricultural potential can vary significantly depending on the local climate and management practices. Additionally, due to their widespread occurrence, Inceptisols contribute to supporting various ecosystems, natural habitats, and watersheds worldwide.

CHAPTER III
ALFISOLS

Alfisols are typically forest soils with moderate leaching levels and high fertility. These soils develop well and possess sub-surface horizons where clay accumulates. Alfisols are commonly found in humid and subhumid regions with temperate climates around the world. The equivalent soil classification names for Alfisols in other systems include Mediteran, Luvisol, and Planosol.

Alfisols are a prominent soil order characterized by their development in forested landscapes with moderate levels of leaching and a high degree of fertility. These soils exhibit a well-developed profile with distinct horizons, and one of their defining features is the accumulation of clay in the subsurface horizon. Alfisols are often associated with regions that experience humid and subhumid climates, particularly those with temperate conditions. This soil order is widely distributed across the globe and plays a significant role in supporting various ecosystems and human activities.

Alfisols are one of the dominant soil types in Indonesia. According to Munir (1996), the extent of Alfisols in Indonesia covers approximately 12,749,000 hectares, spread across the islands of Java, Sumatra, Kalimantan, Sulawesi, Papua, Bali, West Nusa Tenggara, and East Nusa Tenggara.

Covering approximately 10.1% of the Earth's land area, Alfisols are found in regions that are home to about 17% of the world's population. The combination of favorable climatic conditions and high fertility levels contributes to Alfisols being highly productive and suitable for various land uses, including agriculture. These soils provide essential nutrients and moisture-retaining properties, making them ideal for supporting crop growth and sustainable agricultural practices.

Overall, Alfisols are essential components of ecosystems and agricultural landscapes due to their fertility, favorable moisture retention capabilities, and wide distribution. These soils play a vital role in sustaining vegetation, supporting biodiversity, and contributing to food production. Understanding the characteristics and distribution of Alfisols is crucial for informed land management and sustainable agricultural practices, as well as for addressing challenges related to soil degradation, erosion, and the preservation of natural resources.

Alfisols are a type of soil that are characterized by their sandy loam to sandy clay loam texture and moderate to well-drained properties (Barouchas & Moustakas, 2010). These soils are typically found in regions with Mediterranean climatic characteristics, such as South Africa and Australia (Barouchas & Moustakas, 2010). However, Alfisols are known to have low soil fertility rates, low soil pH, and low nutrient content, including nitrogen, phosphorus, potassium, and organic carbon (Samanhudi *et al*., 2021). They are also prone to erosion and have high mass density and erosion sensitivity (Samanhudi *et al*., 2021).

The degradation of Alfisols can have significant impacts on agricultural production and ecosystem services. Soil degradation processes, such as accelerated erosion, depletion of the soil organic carbon pool, and loss of soil fertility, can lead to a decline in soil quality and a decrease in ecosystem goods and services (Lal, 2015). However, it is possible to reverse soil degradation trends by adopting restorative land use practices and recommended management practices (Lal, 2015). These practices aim to minimize soil erosion, enhance soil biota diversity, improve soil structure, and increase the soil organic carbon pool (Lal, 2015).

In addition to their agricultural importance, Alfisols also play a role in environmental processes. For example, studies have shown that Alfisols can contribute to nitrous oxide emissions, a potent greenhouse gas, when fertilizers are applied (Ramu *et al*., 2012). The emission factor for fertilizer-induced nitrous oxide emissions from Alfisols has been found to be 0.90% (Ramu et al., 2012). Furthermore, Alfisols can be affected by heavy metal contamination, which can lead to a reduction in the abundance of ammonia oxidizing bacteria and archaea (Subrahmanyam et al., 2014).

To mitigate the challenges associated with Alfisols, various strategies have been proposed. One approach is the use of soil amendments, such as biochar, to improve soil health and fertility (Liu *et al*., 2022). Studies have shown that biochar amendments can enhance soil microbial community complexity, increase soil fertility, and improve crop growth and quality (Liu *et al*., 2022). Additionally, conservation agriculture practices, integrated nutrient management, and continuous vegetative cover can also contribute to the restoration of soil quality in Alfisols (Lal, 2015).

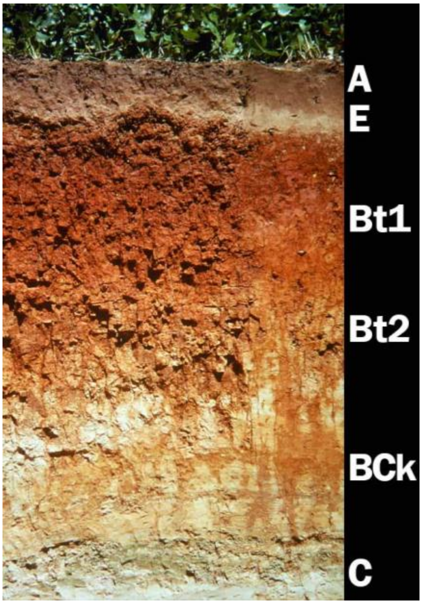


Figure 12. The Profile of Alfisols

3.1. ALFISOL SUBORDER CLASSIFICATION

Alfisols can be further classified into five suborders, each reflecting specific variations in soil characteristics and regional conditions. The Aqualfs suborder, for instance, indicates soils with a high water table or those that are frequently saturated, while the Cryalfs suborder represents soils with cold climates where cryogenic processes have influenced their development. The Udalfs suborder refers to soils with a humid climate and well-developed profiles, while the Ustalfs suborder includes soils with moderate climatic conditions and a prominent subsurface horizon enriched with clay. Lastly, the Xeralfs suborder signifies soils found in areas with a pronounced dry season or semi-arid climates.

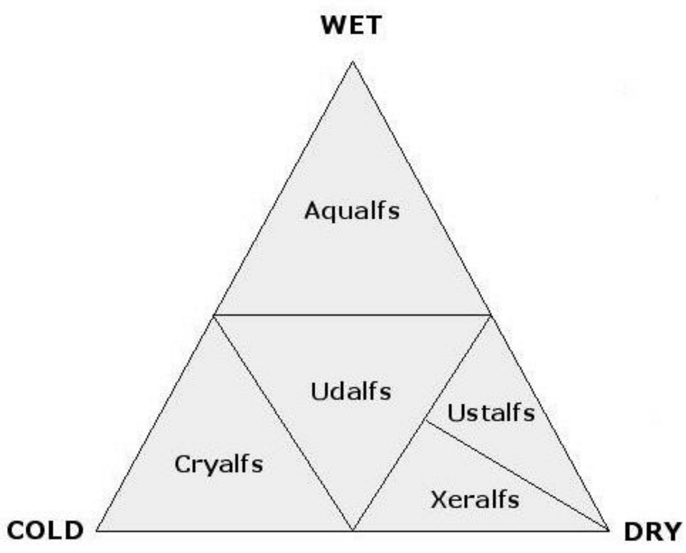


Figure 13. Suborder Diagram of Alfisols

Description:

Aqualfs	-	Alfisols with a water table at or near the surface for much of the year
Cryalfs	-	Alfisols of cold climates
Ustalfs	-	Alfisols of semiarid and subhumid climates
Xeralfs	-	Temperate alfisols with very dry summers and moist winters
Udalfs	-	Alfisols of humid climates

Aqualf Suborder

The Aqualf suborder is a distinctive classification within the Alfisol soil order, characterized by its association with high water tables or frequent saturation. These soils are typically found in areas with excess moisture, such as wetlands, floodplains, and regions that experience seasonal flooding. The Aqualf suborder plays a crucial role in water and nutrient cycling, and its unique properties have significant implications for land use and management.

One of the key characteristics of Aqualf soils is their periodically saturated condition, which has a profound impact on soil properties and nutrient dynamics. The waterlogged environment in which Aqualf soils develop leads to reduced oxygen availability in the subsurface horizons, creating conditions conducive to unique biochemical reactions. These reactions can result in the accumulation of specific minerals and the release of certain elements that influence the overall fertility and chemistry of the soil.

Aqualf soils exhibit distinctive horizon development, with signs of reduction and iron enrichment in the subsurface. The fluctuating water levels play a role in the movement of iron and other elements, contributing to the development of unique color patterns and soil structures. Due to their hydrology-driven properties, Aqualf soils often have excellent water-holding capacity, which can be beneficial for sustaining plant growth during dry periods.

While Aqualf soils offer advantages in terms of water retention and nutrient cycling, their waterlogged nature can also present challenges for agricultural activities. Drainage management is often essential to prevent waterlogging and improve soil aeration, allowing for healthier root development and reducing the risk of certain plant diseases. Additionally, the presence of excess water can lead to leaching of nutrients, which may require careful nutrient management strategies for sustainable crop production.

In ecosystems, Aqualf soils provide critical habitat for specialized vegetation and support diverse plant and animal communities adapted to wet conditions. These soils contribute to the overall ecological health of wetlands and floodplain areas, playing a role in flood control, groundwater recharge, and maintaining water quality. Understanding the unique characteristics and functions of Aqualf soils is essential for effective land management decisions, particularly in areas prone to flooding or with high water tables.

Cryalf Suborder

The Cryalf suborder is a significant classification within the Alfisol soil order, and it is characterized by its formation in cold climates with permafrost or a history of permafrost. These soils are found in regions where the ground remains frozen for extended periods, impacting their physical and chemical properties. Cryalf soils have unique characteristics that result from the freeze-thaw processes and the influence of cold temperatures on soil development.

One of the distinguishing features of Cryalf soils is the presence of permafrost, which is defined as soil or rock that remains below freezing for two or more consecutive years. Permafrost profoundly affects soil properties, including drainage, nutrient availability, and organic matter decomposition. Cryalf soils often exhibit a pattern of vertical segregation due to the freeze-thaw cycles. The active layer, which thaws during the summer, is underlain by permanently frozen soil or rock material.

The freezing and thawing of Cryalf soils lead to soil expansion and contraction, which can result in the formation of ice lenses, cracks, and distinctive soil structures. These processes contribute to soil mixing and the redistribution of soil particles. As a result, Cryalf soils often have well-developed horizon characteristics, such as illuvial accumulation of clay in the B horizon due to the downward movement of minerals during thaw periods.

Due to their formation in cold climates, Cryalf soils tend to have slower organic matter decomposition rates, leading to the accumulation of organic materials in the soil profile. This accumulation can create a surface organic horizon (O horizon) with relatively high organic content. The limited decomposition is primarily a result of the cold temperatures and reduced microbial activity associated with permafrost conditions.

The presence of permafrost can also affect land use and infrastructure development. Buildings, roads, and other structures can be impacted by the thawing of permafrost, leading to subsidence and ground instability. In terms of agriculture, Cryalf soils present unique challenges due to their cold temperatures, short growing seasons, and limited nutrient availability. However, with appropriate management practices and technologies, some agricultural activities can be carried out in these areas.

Ustalf Suborder

The Ustalf suborder is a prominent classification within the Alfisol soil order, known for its widespread occurrence in regions with a distinct seasonal climate. These soils are primarily found in areas characterized by a warm to hot summer and a distinct wet and dry season, making them well-suited for various agricultural activities. Ustalf soils are known for their distinctive horizon development and nutrient dynamics that result from the interplay of climate, vegetation, and soil-forming processes.

One of the key features of Ustalf soils is their well-defined horizon development. The soils typically exhibit a distinct A horizon (topsoil) enriched with organic matter and nutrients due to the accumulation of plant debris and microbial activity. Below the A horizon, there's a B horizon (subsoil) where minerals and nutrients leach and accumulate. This horizonation pattern reflects the seasonal cycling of moisture and nutrient movement within the soil profile.

The Ustalf suborder is further classified into subgroups based on specific soil properties and characteristics. Different Ustalf subgroups may exhibit variations in texture, nutrient content, and horizon development, reflecting the diversity of soil-forming factors and climatic conditions in different regions. These subgroups include Argiustolls, Cambiustolls, Haploustrolls, and Paleustolls.

Ustalf soils are often well-suited for agriculture due to their favorable climate and nutrient availability. The distinct wet and dry seasons provide an opportunity for farmers to schedule irrigation and cultivation activities effectively. The combination of warm temperatures and sufficient moisture during the growing season supports the development of crops, making Ustalf soils important contributors to global food production.

However, like any soil type, Ustalf soils come with their own challenges and management considerations. Erosion can be a concern during the wet season when heavy rainfall occurs, potentially leading to nutrient loss and reduced soil productivity. Proper soil conservation practices, such as cover cropping and contour farming, are crucial to mitigate erosion risks and maintain soil health.

Xeralf Suborder

The Xeralf suborder is an important classification within the Alfisol soil order, known for its occurrence in regions characterized by a dry and arid climate. These soils develop in areas where water availability is limited, and they play a crucial role in supporting vegetation and agricultural activities in challenging environments.

Xeralf soils are distinguished by their specific horizon development and nutrient dynamics, shaped by the arid climate they form in. The soils typically have a well-defined A horizon (topsoil) enriched with organic matter and nutrients, as well as a B horizon (subsoil) where minerals and nutrients accumulate due to limited leaching. This unique horizonation pattern reflects the scarcity of water that limits the downward movement of nutrients and minerals.

Within the Xeralf suborder, various subgroups exist that represent different characteristics and properties. These subgroups include Argixerolls, Calcixerolls, Gypsisols, Haploxerolls, and Petroxerolls. Each subgroup has specific features that reflect the influence of parent materials, climate, and vegetation on soil development.

Xeralf soils play a significant role in supporting vegetation adapted to arid conditions, such as drought-resistant plants and desert flora. They also have potential for agricultural use, especially with proper irrigation techniques and water management practices. Due to the limited water availability, efficient water use and conservation strategies are essential to maintain soil productivity and crop growth.

Soil erosion can be a concern in Xeralf soils due to the arid climate, which often leads to sporadic heavy rainfall and flash floods. This can result in the loss of topsoil and nutrients, impacting soil fertility and agricultural productivity. Implementing erosion control measures and utilizing practices like contour farming can help mitigate these risks.

Udalf Suborder

The Udalf suborder is a significant classification within the Alfisol soil order, known for its presence in areas with more humid and moderate climate conditions. These soils are characterized by their unique properties that develop as a result of the interplay between climate, vegetation, and soil-forming processes in regions with higher moisture availability. Udalf soils are prevalent in various parts of the world and have important implications for agriculture and land use.

Udalf soils are characterized by their distinct horizon development, with a well-defined A horizon (topsoil) that accumulates organic matter and nutrients from plant residues. This horizon is enriched with minerals and nutrients as a result of the leaching process that occurs due to higher rainfall. The B horizon (subsoil) may show evidence of clay illuviation and mineral accumulation, further influencing soil fertility and nutrient availability.

Within the Udalf suborder, different subgroups may exist, each reflecting specific soil properties and adaptations to local conditions. These subgroups include Hapludalfs, Aquudalfs, and Udifluvents, which may vary in texture, drainage characteristics, and other attributes based on the local environment.

Udalf soils are often utilized for agricultural purposes due to their relatively high fertility and moisture-retaining capacity. The presence of well-developed topsoil and the availability of nutrients make them suitable for various crops. However, proper management practices are crucial to maintain soil health and prevent issues such as erosion and nutrient leaching.

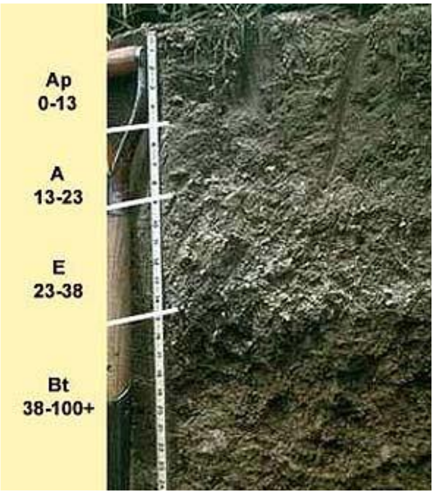
Conservation measures, such as cover cropping, contour farming, and proper irrigation techniques, play a pivotal role in sustainable land management for Udalf soils. These practices help protect the soil structure, minimize nutrient loss, and enhance water retention capabilities. Additionally, understanding the specific subgroup characteristics within the Udalf suborder is essential for tailoring management strategies to local conditions.

FIGURE 14
THE AQUALF SOIL PROFILE AND LANDSCAPE

The Landscape of Albaqualf

This soil is typically found in grassland areas in central Missouri. The land is used for producing corn, soybeans, and sorghum. This photo shows a harvested corn field in winter. The soil remains saturated with water from winter to spring. Excessive water conditions pose challenges in the use and management of this soil.

The Profile of Mollic Albaqualf



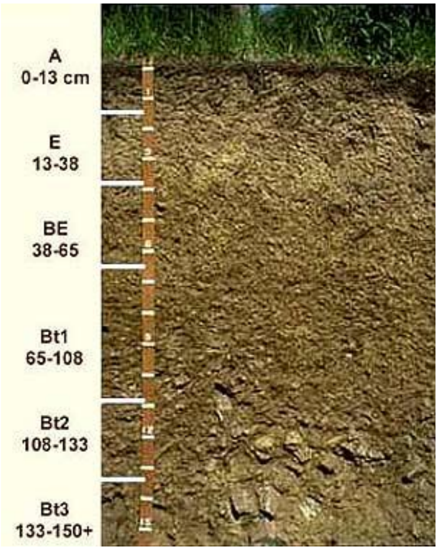
This soil is formed from loose parent material with clay content ranging from 16% in the Ap horizon to 59% in the Bt horizon. Due to the clay-rich subsoil, the soil becomes saturated with water during winter and spring, which poses challenges in its use and management. With artificial irrigation, this soil is primarily utilized for the production of agricultural commodities such as corn, soybeans, and sorghum.

FIGURE 15
THE CRYALF SOIL PROFILE AND LANDSCAPE

The Landscape of Haplocryalf

This landscape is a typical type in the southeastern mountains of Idaho. These soils are primarily used for timber production, livestock farming, and outdoor recreation.

The Profile of Typic Haplocryalf



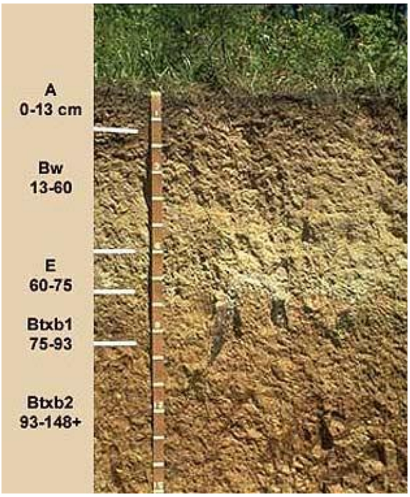
This land is found at an altitude of 1980 m to 2400 m. The natural vegetation is pine, ferns, cypress, and grasses. The soil is formed from loose limestone residue. Due to the large leaching rate, calcium carbonate is mostly only present in the lowest few subsoil horizons. These lands are primarily used for timber production; However, some land is used for livestock. This land is unproductive agricultural land due to the short growing season.

FIGURE 16
THE XERALF SOIL PROFILE AND LANDSCAPE

The Landscape of Fragixeralf

This landscape is a typical type in southern Idaho. Originally, parts of the existing forests were cleared for agricultural activities in the 19th century. The average annual rainfall is about 700 mm. These soils have very low permeability and limited root depth due to the presence of a fragipan subsoil. The occurrence of seasonal groundwater above the fragipan usually happens from December to May.

The Profile of Vitrandic Fragixeralf



This soil is entirely formed on dusty and loose textures. Its natural vegetation includes pine trees. The fragipan subsoil has a bulk density of around 1.8 g/cm3, making it a challenge for the use and management of this soil. The presence of a saturation zone above the fragipan during the winter to spring seasons leads to erosion disasters in steep slope areas. Land use planning for this soil should be conducted to calculate erosion and manage nutrient elements in the soil that occur due to this saturation zone.

3.2. THE GLOBAL DISTRIBUTION OF ALFISOLS

Alfisols, a soil order characterized by moderate leaching and substantial fertility, exhibit a widespread global distribution. These soils play a crucial role in supporting agricultural activities and ecosystems in various parts of the world. Alfisols are particularly prevalent in regions with temperate and subtropical climates, where they are associated with forested landscapes and contribute to sustaining agricultural productivity.

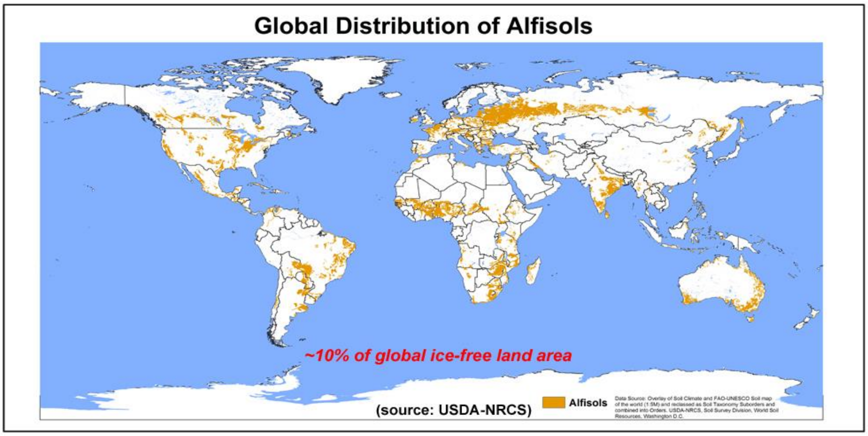


FIGURE 17. The Global Distribution of Alfisols

In North America, Alfisols are abundant across the United States, spanning from the eastern seaboard to the Midwest. The fertile soils of the American Midwest, often referred to as the "Corn Belt," are largely composed of Alfisols, making this region a major agricultural hub. In South America, countries like Brazil, Argentina, and Chile harbor extensive areas of Alfisols, mainly in their southern regions.

In Africa, Alfisols are found in diverse countries such as Nigeria, Kenya, Ethiopia, and Sudan. These soils are crucial for supporting agricultural activities and food security in the continent. In Europe, Alfisols are present in countries like France, Germany, and Ukraine, contributing to the continent's agricultural productivity and land use.

In Asia, Alfisols can be observed in countries like China, India, and Japan. These soils are often associated with rice cultivation and other staple crops, playing a pivotal role in food production for densely populated areas. Oceania also features Alfisols, with Australia being a notable example. The fertile soils of Australia's eastern coast are Alfisols, supporting a range of agricultural endeavors.

The global distribution of Alfisols reflects their adaptability to a variety of climates and parent materials. Their prevalence in regions with moderate leaching and ample organic matter accumulation underscores their significance in sustaining both natural ecosystems and human societies. As a key player in global agriculture, Alfisols contributes to food security and economic stability in numerous countries around the world.

CHAPTER IV
MOLLISOLS

Mollisols are soils in grassland ecosystems. These soils are characterized by a thick and dark surface horizon. This fertile surface horizon is known as the mollic epipedon, formed through the accumulation of organic matter over a long period originating from plant roots. Mollisols primarily occur in mid-latitude regions and extensive grassland areas. Globally, these soils cover 7% of the land area. Mollisols are among the most important and productive agricultural soils worldwide and are extensively utilized for such purposes. Equivalent soils to Mollisols in other classification systems include Phaeozem, Chernozem, and Renzina.

Mollisols are a distinctive soil order that plays a vital role in supporting agricultural productivity around the world. These soils are primarily associated with grassland ecosystems and are recognized for their unique characteristics that make them highly fertile and suitable for cultivation. One of the defining features of Mollisols is the presence of a thick, dark-colored surface horizon known as the mollic epipedon. This horizon is formed due to the accumulation of organic matter derived from plant residues over a long period. As a result, Mollisols possess excellent soil structure and nutrient-retaining capabilities.

These soils are especially prominent in regions with temperate climates, occupying substantial areas in North America, Eastern Europe, and parts of Asia. Their global distribution covers around 7% of the Earth's land surface. The inherent fertility of Mollisols stems from their high levels of organic matter and essential nutrients like calcium and magnesium, making them highly conducive for agriculture. They are particularly suited for growing crops like grains, vegetables, and legumes due to their exceptional water-holding capacity and nutrient availability.

In terms of their geographical distribution in Indonesia, Mollisols covers approximately 9.91 million hectares, accounting for 5.3% of the country's total land area. These soils are found across several provinces, including Papua, East Nusa Tenggara, Maluku, East Kalimantan, Central Sulawesi, and East Java. Their presence in these regions reflects their adaptability to diverse climatic and geographic conditions, demonstrating their importance as a potential resource for agricultural development. It is found in Papua (5.75 million ha), East Nusa Tenggara (1.05 million ha), Maluku (0.53 million ha), East Kalimantan (0.52 million ha), Central Sulawesi (0.39 million ha), and East Java (0.37 million ha).

Mollisols are a type of soil that is characterized by a thick, dark-colored surface horizon known as a mollic epipedon (Jelinski *et al*., 2019). They are highly fertile and are known for their high organic matter content, high cation exchange capacity, and good water-holding capacity (Nichols, 2006). Mollisols are commonly found in grassland ecosystems, where they play a crucial role in supporting agricultural productivity (Nichols, 2006). They are particularly well-suited for growing crops such as corn, wheat, and soybeans (Yan *et al*., 2014).

The formation of Mollisols is influenced by factors such as climate, vegetation, and parent material (Schimel *et al*., 1994). They are typically found in regions with a semi-arid to sub-humid climate, where there is a balance between precipitation and evapotranspiration (Li *et al*., 2022). The presence of grassland vegetation, with its high root biomass and input of organic matter, contributes to the development of the characteristic mollic epipedon (Nichols, 2006).

Erosion can have a significant impact on the classification of Mollisols. High erosion rates can lead to the loss of the mollic epipedon, resulting in the reclassification of these soils as Inceptisols or Entisols (Jelinski *et al*., 2019). This highlights the vulnerability of Mollisols to changes in their diagnostic features under erosive conditions (Jelinski *et al*., 2019). Efforts to mitigate erosion and preserve the integrity of Mollisols are crucial for maintaining their fertility and agricultural productivity (Thomas, 2012).

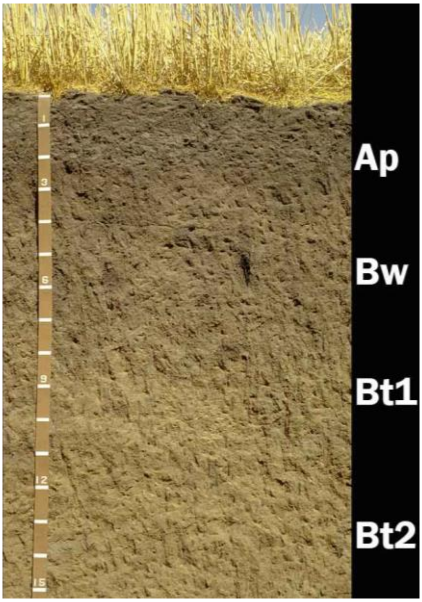


Figure 18. The Profile of Mollisols

4.1. MOLLISOL SUBORDER CLASSIFICATION

Mollisols are subdivided into eight suborders based on specific characteristics and variations in their development. These suborders include Albolls, Aquolls, Rendolls, Gelolls, Cryolls, Xerolls, Ustolls, and Udolls. Each suborder represents variations in soil properties such as drainage, moisture retention, and nutrient availability. These distinctions play a crucial role in determining the suitability of Mollisols for various types of crops and land uses, contributing to sustainable agricultural practices and food production.

Description:

Albolls	-	A wet Mollisol with a bright-colored C horizon is formed through iron reduction
Aquolls	-	A Mollisol with groundwater near the surface almost throughout the year
Rendolls	-	A shallow Mollisol with fragile parent material
Gelolls	-	A Mollisol in a very cold climate (average annual soil temperature <0°C)
Cryolls	-	A Mollisol in a cold climate region

Xeroll	-	In areas with a moderate climate, characterized by very dry summers and wet winters
Ustoll	-	Mollisol in areas with a semiarid and subhumid climate
Udoll	-	Mollisol in humid climate areas

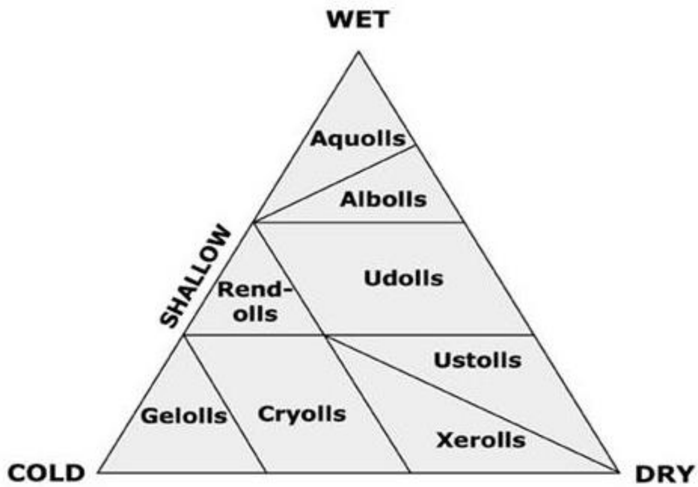


Figure 19. Suborder Diagram of Mollisols

Alboll Suborder

The Alboll suborder is a distinct classification within the Mollisol soil order, characterized by its unique properties and formation processes. Albolls are known for their prominent accumulation of clay and organic matter in the subsoil horizon, contributing to their distinctive properties. These soils are commonly found in regions with high levels of precipitation and lush vegetation, where organic matter input is substantial.

Alboll soils typically exhibit a dark-colored A horizon, enriched with organic materials derived from plant and microbial activity. The subsurface B horizon is characterized by its accumulation of clay, iron, and aluminum compounds, creating a distinct color contrast. This clay accumulation, known as illuviation, is one of the defining features of Albolls. The leaching of materials from the upper horizons to the lower horizons contributes to the soil's unique structure and fertility.

The formation of Alboll soils is influenced by the complex interplay of climatic, biological, and geological factors. The process often begins with the decomposition of organic materials in the surface horizons, leading to the downward movement of nutrients and clay particles. In regions with high rainfall, leaching of minerals occurs, further enriching the subsoil with clay. These soils are commonly found in areas with abundant vegetation and significant plant litter accumulation.

Albolls are agriculturally valuable due to their fertility and water-holding capacity, making them suitable for various crops. However, these soils can be challenging to manage due to their potential for compaction and erosion when exposed to intensive land use practices. Proper soil conservation techniques are essential to maintain their productivity and prevent degradation.

Aquoll Suborder

The Aquoll suborder is a classification within the Mollisol soil order, which is known for its exceptional ability to retain moisture due to its high water table or periodic saturation. This suborder is characterized by its significant water-holding capacity and its occurrence in regions with consistently high groundwater levels. The term "Aquoll" is derived from "aquo," indicating the presence of abundant water.

Aquolls are typically found in areas with a humid climate or in regions where the water table is relatively close to the soil surface for a considerable part of the year. These soils are often found in low-lying areas such as floodplains, riverbanks, and other locations where the water table interacts closely with the soil profile. The presence of a high-water table contributes to the unique properties of Aquolls, such as well-drained surface layers and subsoils with more clay and organic matter.

Due to the consistent presence of water, Aquolls have distinct soil horizons. The upper horizon, known as the mollic epipedon, is enriched with organic matter from the decomposition of plant material in periodically water-saturated conditions. This horizon contributes to the soil's fertility and its potential for agricultural use.

However, drainage can be a concern in some cases, and proper management practices are necessary to ensure successful crop growth without waterlogging.

The Aquoll suborder is crucial for agriculture, as the high water holding capacity allows for reliable water availability during dry periods. These soils are commonly used for growing crops such as rice, as well as various other agricultural activities. Management practices that focus on maintaining proper drainage and preventing waterlogging are essential to make the most of the Aquoll soils' inherent advantages. Overall, the Aquoll suborder plays a vital role in supporting agricultural productivity in regions with abundant water resources.

Rendoll Suborder

The Rendoll suborder is a classification within the Mollisol soil order, known for its unique properties and occurrence in specific environmental conditions. Rendolls are characterized by their reddish coloration, which is indicative of the presence of iron oxide, a result of weathering and soil formation processes. The name "Rendoll" is derived from "reddish," reflecting the dominant coloration of these soils.

Rendolls are typically found in regions with a semi-arid to arid climate, where moisture availability is limited, and evaporation rates are high. These soils often occur in areas where the parent material is rich in iron and lacks significant leaching due to the dry conditions. The reddish coloration of Rendolls is a visual indicator of the accumulation of iron oxide coatings on soil particles. The high iron content also contributes to the structural stability of the soil.

One distinctive feature of Rendolls is their relatively shallow depth, often associated with the arid environment in which they form. The soil profile usually consists of a thin surface horizon with a reddish hue and a lower horizon with less intense coloration. These soils tend to have low organic matter content and limited water-holding capacity, which can pose challenges for agricultural activities. However, with proper management practices, Rendolls can be used for various crops and agricultural activities.

Due to their unique characteristics, Rendolls require specific management strategies to optimize agricultural productivity. Conservation practices that focus on retaining moisture and preventing erosion, such as the use of cover crops and contour farming, are often employed. Additionally, irrigation techniques and proper crop selection are crucial for successful cultivation on Rendolls. Their prevalence in semi-arid and arid regions underscores their importance for agriculture and the need for sustainable land management practices.

Geloll Suborder

The Geloll suborder is a distinct classification within the Mollisol soil order, characterized by its specific properties and occurrence in certain environmental conditions. Gelolls are known for their unique gelic features, which result from the influence of permafrost or seasonal frost on soil formation. The term "Geloll" is derived from "gel" and "oll," indicating the presence of frozen or gel-like materials within the soil profile.

Gelolls are typically found in regions with cold climates, where freezing and thawing cycles play a significant role in soil development. These soils often occur in areas with permafrost, where the ground remains frozen for a substantial portion of the year. The presence of permafrost affects soil properties, including drainage, aeration, and nutrient cycling. Gelolls usually have well-drained surface horizons due to the impermeable layer formed by permafrost, which inhibits water movement downward.

One notable feature of Gelolls is the presence of cryoturbation, which refers to the mixing of soil materials caused by the freezing and thawing of water in the soil. This process results in the formation of distinct layers or patterns within the soil profile, contributing to the unique morphology of Gelolls. The freezing and thawing cycles also influence the distribution of organic matter, minerals, and soil particles, shaping the soil's physical and chemical properties.

Due to their occurrence in cold climates with challenging environmental conditions, Gelolls present specific challenges for land use and agriculture. The presence of permafrost and frost-related processes can limit root penetration and nutrient availability for plants. As a result, agricultural activities on Gelolls require careful consideration of planting schedules, crop selection, and soil management practices that mitigate the effects of freezing and thawing cycles.

Cryoll Suborder

The Cryoll suborder is a distinct classification within the Mollisol soil order, characterized by its formation in extremely cold climates where permafrost and frost-related processes significantly influence soil development. The term "Cryoll" is derived from "cryo," referring to the presence of frozen materials, and "oll," indicating Mollisol soil properties. Cryolls are predominantly found in polar and subpolar regions, where freezing temperatures persist for most of the year.

One of the defining features of Cryolls is the presence of continuous permafrost, which extends throughout the soil profile and even deeper into the ground. This permafrost layer has a profound impact on the soil's properties, including its texture, structure, and drainage characteristics. Cryolls often have well-drained surface horizons due to the impermeable layer formed by the permafrost, which restricts water movement downward and leads to the development of shallow groundwater levels.

Cryoturbation is a key process in the formation of Cryolls, where the freeze-thaw cycles cause the soil materials to be mixed and rearranged. This results in the formation of characteristic soil patterns, known as cryogenic soil structures, that are indicative of repeated freezing and thawing events. Cryoturbation can lead to the vertical movement of minerals, organic matter, and other soil constituents, creating distinct horizons and layers within the soil profile.

The extreme cold and frost-related processes present challenges for agriculture and land use on Cryolls. The continuous permafrost layer can restrict root penetration and nutrient availability for plants, making it difficult to establish and maintain vegetation. Additionally, the freeze-thaw cycles can lead to heaving of the soil surface, which further disrupts plant growth and root anchorage. However, Cryolls can support specialized vegetation adapted to these harsh conditions, such as tundra plants.

Xeroll Suborder

The Xeroll suborder is a significant classification within the Mollisol soil order, characterized by its formation in arid and semi-arid climates where water availability is limited. The term "Xeroll" is derived from "xero," meaning dry, and "oll," indicating Mollisol soil properties. These soils play a crucial role in regions where water scarcity is a prevailing environmental factor.

One of the primary defining features of Xerolls is their adaptation to dry conditions. These soils often have relatively low organic matter content and lack distinct horizons due to limited leaching and organic matter accumulation. Their texture can range from sandy to loam, which influences their water-holding capacity and drainage characteristics. Xerolls typically exhibit a weak structure and can be prone to erosion, especially in areas with erratic rainfall.

Xerolls undergo specific soil-forming processes adapted to arid environments. The limited water availability leads to reduced leaching and downward movement of minerals, resulting in the accumulation of soluble salts in the surface layers of the soil profile. This phenomenon is known as salinization, and it can have a significant impact on soil fertility and plant growth. Xerolls also often develop a subsurface horizon called a "kandic horizon," which is enriched with clay and iron, contributing to the unique properties of these soils.

Despite their challenges, Xerolls have been used for various land uses such as dryland farming, grazing, and range management. Sustainable agriculture practices, including water conservation, crop rotation, and soil cover management, are crucial for managing Xerolls and minimizing soil degradation. Additionally, these soils play a role in the preservation of arid ecosystems and provide habitats for specialized flora and fauna adapted to harsh conditions.

Ustoll Suborder

The Ustoll suborder is a distinct classification within the Mollisol soil order, characterized by its formation in regions with a temperate climate and moderate moisture availability. The term "Ustoll" derives from "ust," indicating the presence of an argillic (clay-enriched) horizon, and "oll," which signifies Mollisol soil properties. These soils are typically found in areas with a balance between moisture and temperature, making them suitable for various agricultural activities.

One of the defining features of Ustolls is the development of an argillic horizon, also known as a clay-rich horizon. This horizon forms due to the accumulation of clay minerals from leached materials that migrate downward and accumulate in the subsoil. The presence of the argillic horizon enhances the soil's water-holding capacity and nutrient retention, making Ustolls fertile and suitable for agriculture.

Ustolls are commonly used for intensive crop production, including grains, vegetables, and fruits. The combination of a temperate climate, sufficient moisture, and well-drained soil structure contributes to their suitability for agriculture. However, proper soil management practices are essential to prevent compaction, erosion, and nutrient depletion.

The geographic distribution of Ustolls is widespread, occurring in various parts of the world with temperate climates. These soils are prevalent in regions like the Midwestern United States, parts of Europe, and parts of China. Their adaptability and fertility have made them essential for global food production.

Udoll Suborder

The Udoll suborder is a distinctive classification within the Mollisol soil order, characterized by its occurrence in regions with a temperate climate and a high moisture supply. The term "Udoll" stems from "ud," indicating the presence of a udic moisture regime, and "oll," which signifies Mollisol soil properties. These soils are well known for their suitability for agriculture due to their favorable combination of temperature and moisture conditions.

One of the primary characteristics of Udolls is the development of a udic moisture regime, indicating that these soils experience sufficient moisture throughout the year. This consistent moisture availability contributes to their fertility and ability to support a wide range of crops. The Udolls' high water-holding capacity ensures that crops have access to moisture even during periods of limited rainfall.

Udolls are often found in regions where agriculture is a prominent land use. The combination of a temperate climate, abundant rainfall, and well-drained soil structure makes these soils highly productive. They are particularly suitable for cultivating crops such as grains, fruits, vegetables, and forages.

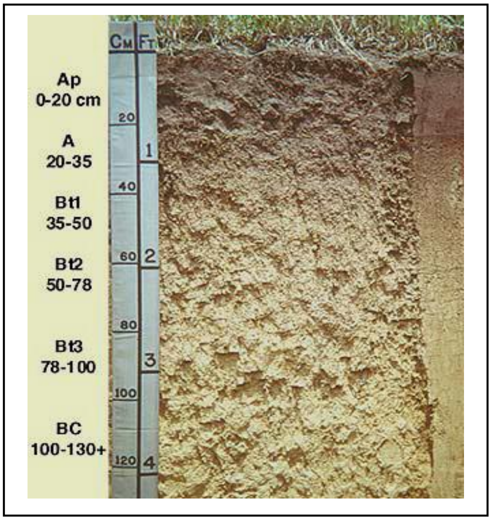
Geographically, Udolls have a broad distribution and are present in various parts of the world with temperate climates and ample rainfall. Regions like the eastern United States, parts of Europe, and certain areas in Asia host Udoll soils that support agriculture and contribute to food production.

FIGURE 20
THE UDOLL SOIL PROFILE AND LANDSCAPE

Landscape of Udoll

This soil is found in glacial plains in Central Iowa. Aquolls with poor drainage are spread across the lower landscape, and Udolls are present in the upper areas. In the image, a small portion of Aquolls can be seen in the front, surrounded by Udolls, which cover the majority of the area. These soils are typically used for corn and soybean production.

The Profile of Udoll



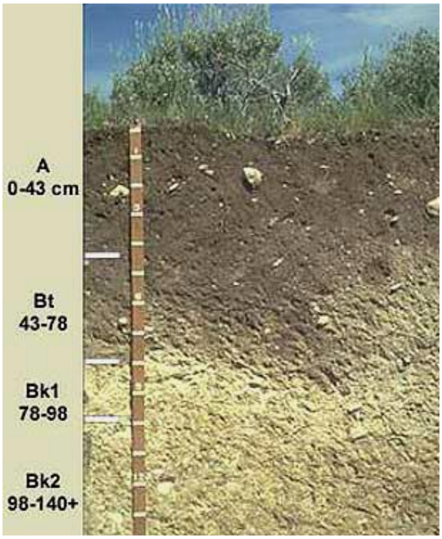
This soil is formed in loose, widely distributed subsoils in SW Iowa, NW Missouri, NE Kansas, and SE Nebraska. Its distribution includes ridge tops, uplands, hillsides, and steep slopes. The soil is formed in tall grass prairies and is now commonly used for agricultural activities such as corn, soybeans, and wheat.

FIGURE 21
THE CRYOLL SOIL PROFILE AND LANDSCAPE

The Landscape of Cryoll

The Argicryoll is visible in the foreground. This soil is formed from the rich ice leachates containing CaCO3 originating from nearby limestone mountains. The cold climate and short growing seasons limit the use of this soil for agricultural activities.

The Profile of Pachic Argicryoll



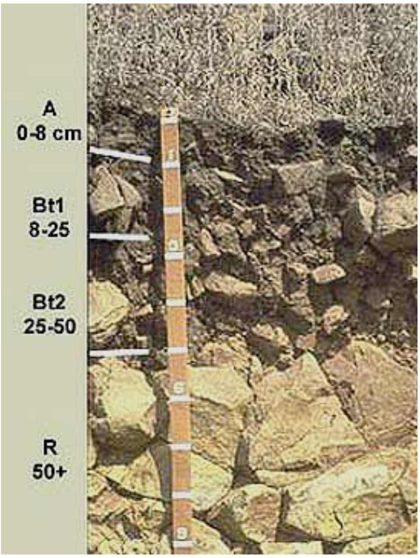
Calcium carbonate in the subsoil originates from the limestone parent material. These minerals dissolve in the upper part of the profile where moisture is higher, leach downward, and deposit in the lower profile with lower moisture. Lateral clay translocation in the upper profile usually initiates the movement of carbonate in this soil. Lateral clay translocation is evidenced by the formation of the Bt horizon. A wavy boundary of horizons can be seen on the right side of the profile. This occurs due to the expansion of soil fauna activity, possibly a type of burrowing animal in this case.

FIGURE 22
THE XEROLL SOIL PROFILE AND LANDSCAPE

The Landscape of Argixeroll

Soils formed on these steep slopes with basaltic rock are typically very shallow but well-developed due to long-term landscape stability. They are widely used for grazing fields. The shallow soil and steep relief with low water-holding capacity significantly limit the use of this land for construction and crop production.

The Profile of Lithic Argixeroll



This soil is formed from a loose mixture with basal colluvium. Horizon Bt contains 27 - 35% clay. This occurs due to the long period of soil formation on a stable land surface, with a warm and humid climate. The percentage of coarse fragments in this soil is usually more than 35%. The high percentage of coarse fragments and the shallowness of the soil limit the total water-holding capacity to around 40-80 mm.

4.2. THE GLOBAL DISTRIBUTION OF MOLLISOLS

Mollisols, characterized by their deep and dark surface horizon, have a widespread global distribution, predominantly found in grassland ecosystems. These soils are known for their high fertility and capacity to support agricultural activities. Mollisols are prevalent in regions with temperate climates and are particularly abundant in the mid-latitudes of North America, Eurasia, South America, and Australia. They cover approximately 7% of the Earth's land area, making them a significant soil order on a global scale.

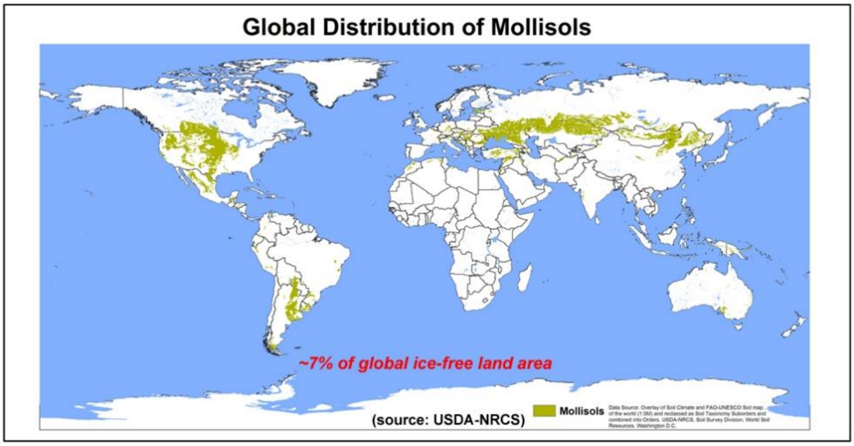


Figure 23. The Global Distribution of Mollisols

In North America, Mollisols are found extensively in the Great Plains of the United States and Canada, forming the fertile soils of the Corn Belt. In South America, they are widespread across the Pampas region, contributing to the agricultural productivity of countries like Argentina and Uruguay. In Europe, Mollisols are found in the Chernozem belt, a region that extends from Ukraine to Russia. These soils have supported centuries of intensive agriculture and are known for their exceptional fertility.

In Australia, Mollisols are found in the temperate grasslands of the southeastern part of the continent. These soils play a crucial role in supporting the country's agricultural activities, particularly in regions where rainfall is relatively reliable. Additionally, Mollisols can also be found in parts of Africa, Asia, and other regions where temperate grassland ecosystems exist.

The presence of Mollisols in these various regions highlights their importance in global food production. These soils have been cultivated for centuries, supporting a range of crops such as wheat, corn, soybeans, and various other grains and legumes. The high organic matter content, deep profile, and good drainage characteristics of Mollisols contribute to their suitability for agriculture and have made them a cornerstone of many societies' agricultural systems around the world.

CHAPTER V
HISTOSOLS

Histosols are soils primarily composed of organic materials. They typically consist of at least 20-30% organic matter by weight and have a thickness greater than 40 cm. The bulk density is relatively low, usually less than 0.3 g/cm3. Most Histosols form under conditions such as wetlands, where restricted drainage prevents the complete decomposition of plant and animal residues, leading to continuous accumulation of organic material. As a result, Histosols play an ecologically significant role due to their substantial carbon content. These soils cover 1.2% of the world's land area and 1.6% in the United States. The equivalent term for Histosols in other soil classification systems is Organosol.

Histosols in Indonesia are distributed across three major islands: Sumatra with a peat area of 5.8 million hectares, Kalimantan with a peat area of 4.5 million hectares, and Papua with a peat area of 3 million hectares.

Histosols, commonly referred to as peat soils, are a unique type of soil characterized by their high organic matter content. They consist of at least 20-30% organic material by weight and typically have a thickness exceeding 40 cm. Their bulk density is relatively low, usually less than 0.3 g/cm^3. Histosols predominantly form in wetland conditions where restricted drainage inhibits the decomposition of plant and animal remains, leading to the continuous accumulation of organic matter. As a result, Histosols play a crucial ecological role due to their substantial carbon content. These soils cover approximately 1.2% of the Earth's land area and 1.6% of the United States.

Histosols are primarily found in areas with high water tables, like marshes, swamps, and bogs. Their unique properties often make them unsuitable for construction purposes due to their low load-bearing capacity and the potential for subsidence upon drainage. These soils have become valuable sources of fuel and are also utilized for agricultural production, especially in regions where drainage and management practices can be implemented effectively.

Histosols are classified into four suborders based on their specific characteristics: Folist, Fibrist, Saprist, and Hemist. Folist Histosols have a relatively high degree of decomposition of organic materials, resulting in a distinctive dark color. Fibrist Histosols have a fibrous structure with moderately decomposed organic matter. Saprist Histosols have highly decomposed organic matter, often forming peat. Hemist Histosols are intermediate between the other suborders in terms of decomposition and organic matter content.

In various parts of the world, including Indonesia, Histosols have significant socioeconomic and environmental importance. In Indonesia, these soils are distributed across major islands and have been extensively utilized for agriculture, as well as being a substantial source of fuel. However, their drainage, subsidence, and carbon storage dynamics have implications for land management, climate change mitigation, and sustainable land use planning.

Histosols are a type of soil that is characterized by their high organic matter content, typically exceeding 20% (Klemedtsson et al., 2005). These soils are formed from the accumulation of partially decomposed plant material in waterlogged conditions, such as wetlands and peatlands (Klemedtsson et al., 2005). Histosols are commonly found in regions with high precipitation and waterlogging, such as boreal and tropical regions (Klemedtsson et al., 2005). They are known for their dark color and spongy texture.

The high organic matter content in histosols makes them valuable for agricultural purposes. They have excellent water-holding capacity and nutrient retention properties, which can be beneficial for crop growth (Klemedtsson et al., 2005). However, histosols also have some challenges for agriculture, such as low nutrient availability and poor drainage. Proper management practices, such as drainage systems and nutrient supplementation, can help overcome these challenges and maximize the agricultural potential of histosols.

Histosols also play an important role in carbon sequestration and climate regulation. The high organic matter content in histosols allows them to store large amounts of carbon. Peatlands, a type of histosol, are particularly important carbon sinks, storing more carbon per unit area than any other terrestrial ecosystem (Klemedtsson et al., 2005). However, when histosols are drained or disturbed, they can release significant amounts of carbon dioxide and other greenhouse gases, contributing to climate change.

In addition to their agricultural and environmental significance, histosols also have implications for archaeology and paleontology. The waterlogged conditions in which histosols form can preserve organic materials, such as plant remains, pollen, and even human artifacts, for thousands of years (Klemedtsson et al., 2005). This makes histosols valuable for studying past environments and human history.

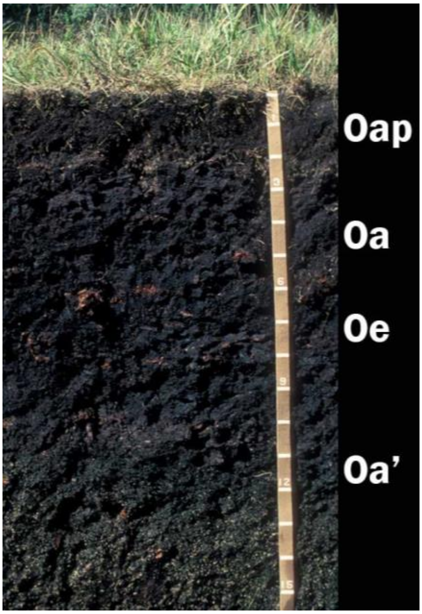


Figure 24. The Profile of Histosols

5.1. HISTOSOL SUBORDER CLASSIFICATION

Histosols, as a distinct soil order, are further classified into four suborders based on specific characteristics related to their degree of decomposition and organic matter content. These suborders help categorize and describe the variations within the Histosol group.

Histosols are classified into four suborders: Folists, Fibrists, Saprists, and Hemists.

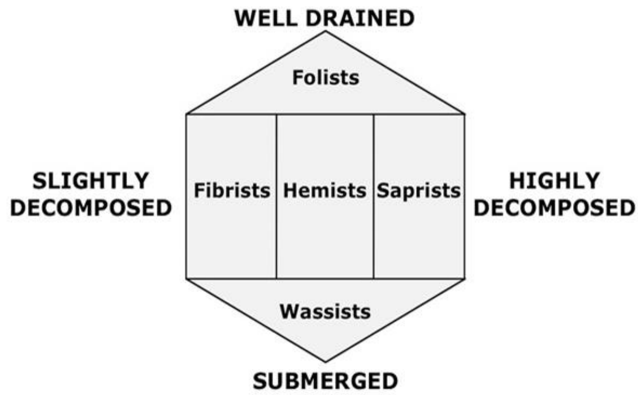


Figure 25. Suborder Diagram of Histosols

Description:

Folists	-	Histosols that are not saturated with water for long periods during the year
Wassists	-	Histosols that are submerged for more than 21 hours every day
Fibrists	-	Histosols that are primarily made up of only slightly decomposed organic materials, often called peat
Saprists	-	Histosols that are primarily made up of highly decomposed organic materials, often called muck
Hemists	-	Histosols that are primarily made up of moderately decomposed organic materials

Folist Suborder

The Folist suborder is a classification within the Histosol order that signifies a distinct stage in the decomposition process of organic materials. Folist Histosols are characterized by a higher level of decomposition compared to other Histosol suborders, resulting in a relatively advanced stage of organic matter breakdown. This decomposition leads to the formation of a dark-colored soil with a recognizable structure, often exhibiting fibrous or fragmentary organic materials.

These soils are typically found in well-drained environments where oxygen availability allows for the breakdown of organic matter. Folist Histosols can be associated with wetlands, marshes, and peatlands that experience regular water table fluctuations and periods of water saturation. Despite the advanced decomposition, some remnants of plant materials may still be visible within the soil.

Due to their relatively high degree of decomposition, Folist Histosols are often less waterlogged compared to other Histosol suborders like Saprist. This characteristic allows them to have better drainage and aeration, making them potentially suitable for certain agricultural activities. However, their relatively low bulk density and high organic content can also make them prone to compaction and subsidence if drainage systems are not properly managed.

In terms of land use, Folist Histosols can have both opportunities and challenges. Their advanced decomposition stage means they can serve as significant reservoirs of carbon and contribute to the overall organic carbon pool. Depending on management practices, Folist Histosols may be utilized for agriculture, especially in areas where drainage systems can be effectively implemented to avoid waterlogging. However, improper land use can lead to degradation, nutrient loss, and potential carbon emissions from the soil.

Wassist Suborder

Wassists are Histosols that are floating on top of free water. Folists are Histosols that formed not due to wet conditions, but from high rates of accumulation of organic matter (relative to decomposition).

Fibrist Suborder

Fibrist is a suborder within the Histosol soil order, characterized by its specific composition and properties. Histosols, commonly referred to as peat or organic soils, are distinguished by their high content of organic matter. The Fibrist suborder of Histosols is defined by its dominance of fibrous plant material, which contributes to its unique characteristics.

Fibrist Histosols are known for containing a significant amount of partially decomposed and recognizable plant fibers, such as roots, stems, and leaves. This fibrous plant material gives the soil a spongy and elastic texture. The suborder's organic content often comprises at least 20-30% of its weight, and its thickness exceeds 40 cm. Fibrist Histosols usually have a low bulk density, typically less than 0.3 g/cm^3.

The formation of Fibrist Histosols occurs in waterlogged or poorly drained environments, where the accumulation of organic matter outpaces its decomposition due to limited oxygen availability. These conditions prevent the complete breakdown of plant remains, resulting in the continuous accumulation of fibrous material over time. As a consequence, Fibrist Histosols play a vital role in carbon storage and sequestration, contributing to the global carbon cycle.

Due to their unique properties, Fibrist Histosols are generally not suitable for construction purposes. They have low load-bearing capacity, and their high water-holding capacity can lead to subsidence when drained. Despite these limitations, these soils have significant agricultural and economic value. Fibrist Histosols are often utilized for agricultural practices, as they can be productive when managed properly. Additionally, they can be harvested for peat extraction and used as a fuel source.

Saprist Suborder

The Saprist suborder is a distinct classification within the Histosol soil order, known for its specific properties and composition. Histosols, commonly referred to as peat or organic soils, are characterized by their high organic matter content. The Saprist suborder of Histosols is defined by the presence of fully decomposed plant material and other organic matter, which contribute to its unique characteristics.

Saprist Histosols exhibit a high degree of decomposition, with the organic material appearing dark and homogeneous. Unlike other suborders within the Histosol order, Saprist soils lack recognizable fibrous or woody plant material. Instead, the organic matter is finely divided and has undergone advanced stages of decomposition.

These soils form in waterlogged or saturated conditions, where the accumulation of organic matter exceeds the rate of decomposition due to limited oxygen availability. This results in the accumulation of peat, which is composed of fully decomposed plant material, mosses, and other organic debris. The peat layer in Saprist Histosols is typically deep and can extend several meters below the surface.

Saprist Histosols have unique properties due to their high organic content, such as their low bulk density and high water-holding capacity. However, they also have limitations, including poor load-bearing capacity and potential for subsidence when drained. Despite these challenges, they have important uses, including agriculture, horticulture, and even carbon sequestration projects.

Hemist Suborder

The Hemist suborder is a distinctive classification within the Histosol soil order, which is characterized by its high organic matter content and specific composition. Histosols, commonly referred to as peat or organic soils, exhibit a range of suborders, each with unique properties. The Hemist suborder is defined by its intermediate stage of decomposition and the specific organic materials present.

Hemist Histosols are characterized by partially decomposed organic matter, often containing both fibrous and amorphous components. This suborder represents an intermediate stage between the more decomposed Saprist Histosols and the less decomposed Fibrists. The partially decomposed organic material gives Hemist soils a unique appearance and structure.

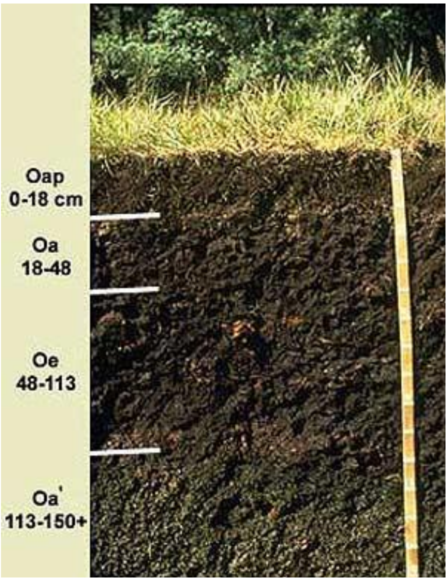
These soils form under waterlogged or saturated conditions, where the accumulation of organic matter outpaces decomposition due to limited oxygen availability. The organic material in Hemist soils is usually a mix of partially decomposed plant matter, mosses, and other organic debris. The resulting peat layer in Hemist Histosols can vary in thickness and composition.

FIGURE 26
THE SAPRIST SOIL PROFILE AND LANDSCAPE

The Landsekap of Haplosaprist

The soil formed in this flat landscape contains minimal mineral content, with almost its entire composition being organic matter. The soil has poor drainage and maintains a high water table throughout the year. If the soil is properly drained and cultivated, its productivity can be quite high.

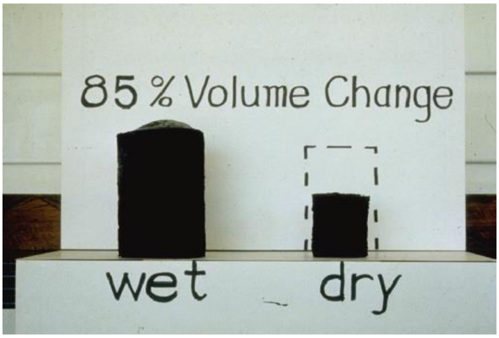
The Profile of Typic Haplosaprist



The organic matter in this soil has decayed, and there are remnants of plant tissues. The advanced stage of this decomposition process is often observed in Histosols with high fluctuations in the water table, where aerobic degradation occurs almost year-round. On the other hand, in fibric peat, this soil is usually referred to as "muck".

FIGURE 27
THE PHENOMENON OF HISTOSOLS

Volume change in dried organic matter



The drying of large organic matter volumes leads to subsidence or land surface settlement in drained Histosols.

Subsidence in drained Histosols

Subsidence in drained Histosols in the Everglades is illustrated by the stake in the center of the image. The stake was installed in 1942 with its tip aligned with the land surface. This image was taken in 1975, and the land had subsided approximately 1.2 meters below the tip of the stake. This indicates subsidence occurring at a rate of about 0.3 meters per decade. In contrast, the rate of organic matter accumulation in Histosols is typically measured in inches per 100 years.

5.2. THE GLOBAL DISTRIBUTION OF HISTOSOLS

Histosols, also known as peatlands or organic soils, exhibit a distinct global distribution primarily found in wetland areas across various regions. The unique properties of Histosols make them significant carbon reservoirs, playing a vital role in global carbon cycling.

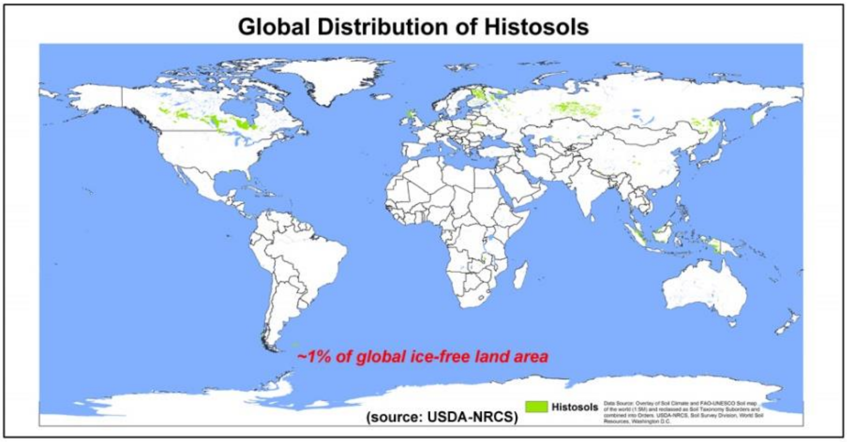


Figure 28. The Global Distribution of Histosols

The distribution of Histosols is closely linked to wetland conditions that impede proper drainage, allowing organic matter to accumulate rather than decompose. These conditions prevail in various climatic zones, including temperate, subarctic, and tropical regions. Peatlands are found in diverse locations, from boreal forests to tropical rainforests, tundras, and even mountainous areas. The distinct hydrological characteristics and environmental settings of these regions contribute to the formation of Histosols.

In Europe, Histosols are prevalent in areas such as the Irish peatlands, the Scottish Highlands, and the boreal forests of Scandinavia. North America hosts extensive peatlands in regions like the Canadian boreal forests, Alaska, and the Everglades in Florida. In Asia, peatlands can be found in the Siberian tundra, parts of China, and Indonesia, where they cover vast expanses in Sumatra, Kalimantan, and Papua.

Despite their widespread distribution, Histosols face challenges due to their unique properties. The accumulation of organic matter makes them susceptible to subsidence, which can result in land sinking and reduced productivity. Land use changes, drainage for agriculture, and peat extraction for fuel can exacerbate these issues, contributing to environmental concerns such as greenhouse gas emissions and habitat loss. The global distribution of Histosols highlights the significance of understanding and managing these unique soils to address both local and global environmental issues.

CHAPTER VI
VERTISOLS

Vertisol is a clay-rich soil with the ability to expand and contract with changes in soil moisture. During dry periods, the soil volume contracts, leading to deep and wide soil cracks. The soil volume then expands as the soil becomes wet. This expansion and contraction activity poses engineering challenges and typically prevents well-developed horizons and shape changes in this soil. The equivalent soil to Vertisol in other classification systems is Grumusol.

Vertisols, characterized by their unique ability to undergo significant changes in volume due to moisture fluctuations, are a distinct type of soil found in various regions around the world. These soils are known for their high clay content, which imparts them with their distinctive properties of shrink-swell behavior. Vertisols are widely recognized for their fascinating ability to crack open during dry periods and then swell and close up when wet, which can lead to challenges in land use and engineering.

The dynamic nature of Vertisols arises from their mineralogical composition, dominated by expansive clay minerals like montmorillonite. When these clays absorb water, they swell and can increase the soil volume by several times, creating unique landscape features characterized by deep cracks during dry spells. These features make Vertisols particularly interesting and sometimes challenging for various human activities.

Vertisols are often highly fertile due to the clay minerals' capacity to retain nutrients and moisture. However, the same clay content that contributes to their fertility can also present obstacles to cultivation and construction. The swelling and shrinking of the soil can lead to uneven surfaces and structural instability, affecting buildings, roads, and other infrastructure.

These soils are found in regions with distinct wet and dry seasons, such as parts of India, Australia, Africa, and the United States.

Vertisols are valuable for agriculture, as they can be incredibly productive when managed properly. Crops like cotton, soybeans, sorghum, and wheat can thrive in Vertisols' fertile and moisture-retentive environment. However, careful management is required to mitigate the challenges posed by their shrink-swell behavior, such as using proper irrigation techniques and land leveling.

Despite the challenges they pose, Vertisols holds promise for sustainable agricultural practices and water management strategies. By understanding the unique properties of these soils, farmers and land managers can harness their potential for increased productivity while minimizing the negative effects of their shrink-swell behavior on infrastructure and land use.

The extent of Vertisol distribution in Indonesia covers approximately 2.1 million hectares (Subagyo et al., 2004 cited in Prasetyo, 2007), dispersed across various regions. These regions include East Nusa Tenggara (0.198 million ha), East Java (0.96 million ha) in areas like Ngawi and Bojonegoro, West Nusa Tenggara (0.125 million ha) on islands like Lombok and Sumbawa, South Sulawesi (0.22 million ha), North Sulawesi, and Central Java (0.4 million ha).

Vertisols are a type of soil that is characterized by their high clay content and ability to shrink and swell with changes in moisture content. They are found in tropical and subtropical regions, with major areas of distribution including eastern Australia, western India, Sudan, and adjacent areas, and parts of the southern USA (Rust & Nanson, 1989). The formation and pedogenesis of vertisols have been extensively studied, with research focusing on mineralogical, micro-morphological, and age-control tools to understand the processes involved (Pal *et al*., 2012).

It has been observed that bedload transport of mud as pedogenic aggregates is a significant process in both modern and ancient rivers, indicating the widespread distribution of vertisols (Rust & Nanson, 1989). In addition, studies have shown that vertisols have unique characteristics that affect groundwater flow and salinity, making them important in hydrological studies (Kurtzman *et al*., 2016). The classification of vertisols in Canada has identified three subgroups: Orthic, Gleyed, and Gleysolic. Sustainable land use and management of vertisols pose challenges due to population pressure and traditional land use practices, but there are opportunities for maintaining soil fertility and productivity while minimizing erosion and degradation (Ikitoo *et al*., 2011). Remote sensing technologies and spatial models have been used to monitor and understand the driving forces of deforestation, including the conversion of vertisols for agricultural purposes (Chowdhury, 2006).

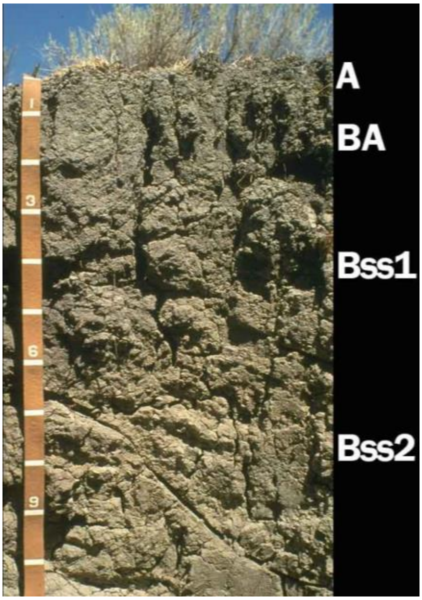


Figure 29. The Profile of Vertisols

6.1. VERTISOL SUBORDER CLASSIFICATION

Vertisols are classified into six suborders based on variations in soil properties and characteristics. These suborders reflect different environmental conditions and soil development processes within the Vertisol order: Aquerts, Cryerts, Xererts, Torrerts, Usterts, and Uderts.

Description:

Aquerts	-	Vertisols with a water table at or near the surface for much of the year
Cryerts	-	Vertisols of cold climates

Xererts - Temperate Vertisols with very dry summers and moist winters

Torrerts - Vertisols of dry climates

Usterts - Vertisols of semiarid and subhumid climates

Uderts - Vertisols of humid climates

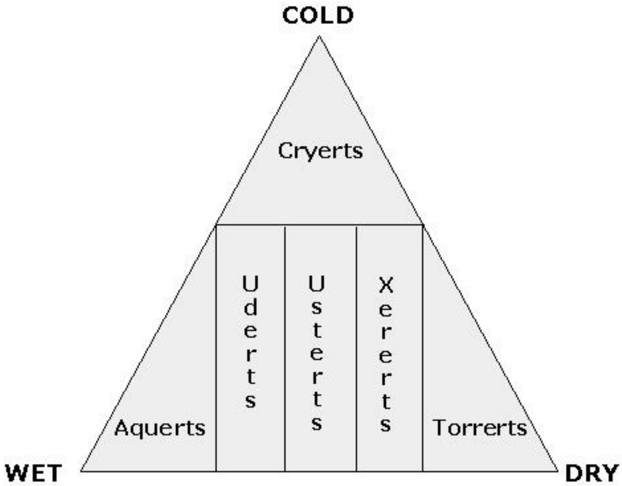


Figure 30. Suborder Diagram of Vertisols

Aquert Suborder

The Aquert Suborder represents a specific category of Vertisols characterized by their interaction with waterlogged conditions during the wet season. These soils exhibit a remarkable ability to shrink and swell in response to changes in moisture levels. The unique behavior of Aquerts is attributed to the alternating wet and dry cycles they experience.

Aquerts are typically found in regions with distinct wet and dry seasons. During the wet season, these soils become waterlogged, leading to the development of deep cracks and fissures as they dry out. The shrinking and swelling properties of Aquerts are most pronounced during this cycle. As the soil dries and cracks form, the moisture penetrates deeper into the soil profile, causing it to swell and close the cracks upon rewetting.

The waterlogging during the wet season results in the accumulation of clay-rich material near the surface, leading to the development of a characteristic clay-enriched horizon. This horizon is responsible for the unique behavior of Aquerts and their ability to undergo significant volume changes. The cracks and fissures formed during the shrinking phase can have significant depths, often extending several feet into the soil.

Due to their waterlogging tendencies, Aquerts can pose challenges for agriculture and construction. The presence of standing water and the development of deep cracks can hinder root penetration and disrupt the stability of structures built on these soils. Drainage management and appropriate agricultural practices are essential to mitigate the challenges posed by Aquerts.

Cryert Suborder

The Cryert Suborder belongs to the Vertisols order of soils and is characterized by its response to cold climatic conditions. These soils exhibit the unique properties of shrink-swell behavior that are typical of Vertisols but with the added influence of cold temperatures. Cryerts are found in areas with pronounced seasonal temperature fluctuations and are often associated with regions experiencing long, cold winters.

One of the defining features of Cryerts is their freeze-thaw cycle, which occurs as the soil undergoes cycles of freezing during the cold months and thawing during the warmer periods. This freeze-thaw action exacerbates the shrink-swell behavior of the soils, leading to the development of deep cracks and fissures when the soil dries out. These cracks can extend several feet into the soil profile and play a significant role in water movement and root penetration.

The freeze-thaw action in Cryerts is responsible for disrupting the natural structure of the soil, leading to the mixing of soil particles and minerals. This mixing can have implications for soil fertility and nutrient availability, as well as affecting the movement of water within the soil. In addition, the freeze-thaw action can lead to soil erosion and the redistribution of soil materials.

Cryerts are often found in areas with cold, continental climates, such as parts of North America and Europe. These soils can be challenging for agricultural practices due to their unique properties. The freeze-thaw cycles can damage plant roots, and the development of cracks can hinder water retention and nutrient availability. Therefore, careful soil management and agricultural practices are necessary to make the best use of Cryert soils for crop production.

Xerert Suborder

The Xerert Suborder is a specific classification within the Vertisols soil order, characterized by its occurrence in arid and semi-arid regions. These soils are uniquely adapted to the challenging conditions of these dry climates, showcasing the distinctive properties of Vertisols while being influenced by the scarcity of water. Xererts are found in areas with limited rainfall and high evaporation rates, making their management and agricultural use particularly interesting.

Xererts exhibit the typical shrink-swell behavior of Vertisols, which is a result of their high clay content and ability to expand when wet and contract when dry. However, in arid and semi-arid environments, the availability of water is limited, leading to more extreme cycles of expansion and contraction. This can result in the development of deep cracks and fissures when the soil dries out, and their subsequent closure when the soil becomes wet.

The soil structure of Xererts is often characterized by the unique arrangement of clays, organic matter, and minerals, which contributes to their capacity to shrink and swell. These properties can affect water infiltration and retention, as well as nutrient availability for plants. In arid regions, where water is scarce, the ability of Xererts to store water during wet periods and slowly release it during dry spells can be advantageous for supporting vegetation.

Xererts are found in various regions around the world, including parts of Africa, Australia, and North America. Their occurrence in arid and semi-arid climates means they are frequently associated with rangeland ecosystems rather than intensive agriculture. However, when managed carefully and supplemented with irrigation, Xererts can support certain types of crops, particularly drought-tolerant plants.

Torrert Suborder

The Torrert Suborder is a classification within the Vertisols soil order that specifically pertains to soils found in regions with pronounced seasonal climates, characterized by alternating wet and dry periods. These soils exhibit the characteristic properties of Vertisols, including their high clay content and the ability to shrink and swell dramatically in response to changes in moisture. However, Torrerts are uniquely adapted to the specific challenges posed by seasonal climatic variations.

Torrerts are commonly found in regions with distinct wet and dry seasons, such as tropical monsoon climates. During the wet season, these soils absorb water and expand, leading to the development of deep cracks and fissures as the soil dries out in the subsequent dry season. These cracks can extend several meters deep and play a significant role in facilitating water infiltration during the wet season.

The seasonal dynamics of Torrerts can have a profound impact on their agricultural use. While they can be challenging to manage due to their tendency to develop deep cracks during the dry season, these cracks can also serve as natural reservoirs for water, enabling plants to access moisture during periods of drought. This unique feature can be advantageous for certain crops and vegetation that are well-adapted to such conditions.

Torrerts are distributed in various parts of the world with distinct seasonal climates, including regions in Asia, Africa, and Australia. These soils are often associated with agricultural practices that are suited to their specific properties. Farmers in areas with Torrerts may employ techniques to manage water availability, such as optimizing planting times to coincide with the wet season or using irrigation to supplement moisture during the dry season.

Ustert Suborder

The Ustert Suborder is a classification within the Vertisols soil order, known for its distinctive characteristics and distribution in regions with specific climatic conditions. Usterts are soils that exhibit the typical properties of Vertisols, including high clay content and the ability to shrink and swell significantly with changes in moisture levels. However, Usterts are specifically associated with a subhumid to humid climate, making them well-suited for regions with relatively consistent moisture availability.

Usterts are characterized by their ability to retain moisture due to their high clay content. These soils are often found in regions where precipitation is relatively abundant, ensuring a consistent water supply for plants and agricultural activities. The unique shrink-swell behavior of Usterts contributes to their water retention capacity, allowing them to hold onto moisture for extended periods.

Agricultural use of Usterts is influenced by their moisture-retaining properties. These soils are particularly suitable for crops that thrive in moist conditions, such as rice, sugarcane, and various types of vegetables. The consistent water availability in Usterts can also be beneficial for sustaining natural vegetation and supporting ecosystems that rely on steady moisture levels.

Ustert soils are distributed across various parts of the world, including regions in Asia, Africa, and the Americas. The presence of Usterts often corresponds with landscapes characterized by relatively high rainfall or proximity to water bodies. In some cases, irrigation systems are utilized to enhance agricultural productivity and manage water resources effectively.

Udert Suborder

The Udert Suborder is a classification within the Vertisols soil order, known for its specific properties and occurrence in regions with distinct climatic and landscape characteristics. Uderts are soils that share the general characteristics of Vertisols, including a high clay content and the ability to undergo significant shrink-swell behavior in response to changes in moisture levels. However, Uderts are specifically associated with arid and semiarid climates, making them prevalent in regions where water availability is limited.

One of the defining features of Uderts is their occurrence in regions with relatively dry conditions. These soils are adapted to areas where water is scarce and fluctuations in moisture levels are common. The shrinkage and swelling of Uderts in response to wet and dry cycles contribute to their unique soil structure and the formation of deep cracks during dry periods.

Due to their arid and semiarid habitat, Uderts are often found in landscapes where water conservation is critical. These soils play a crucial role in capturing and storing water during periods of rainfall, making them essential for water retention and minimizing soil erosion. Their ability to hold onto moisture can contribute to sustaining both natural vegetation and agricultural practices in these challenging environments.

Uderts can support certain crops that are adapted to arid conditions, such as drought-resistant grains and desert vegetation. Their unique soil structure and water-retaining properties make them valuable for agricultural activities in regions with limited water resources. However, effective water management and irrigation practices are essential for maximizing agricultural productivity in Udert soils.

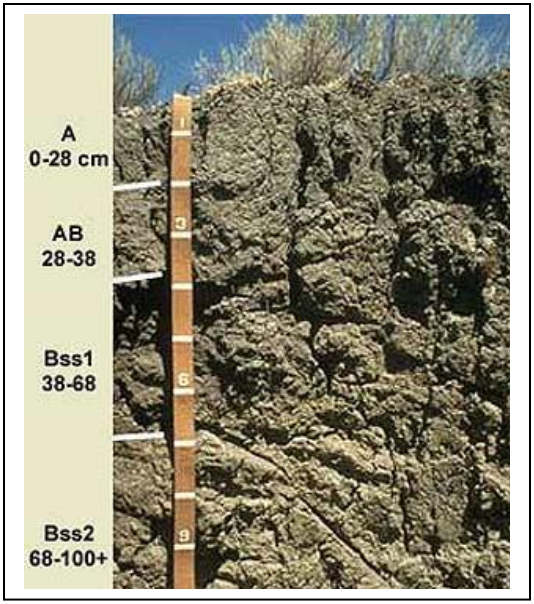
The distribution of Udert soils spans various parts of the world, including arid and semiarid regions on different continents. Understanding the properties and behavior of Uderts is crucial for developing strategies that mitigate the challenges of water scarcity and support sustainable land use practices. These soils underline the close connection between soil characteristics, climate, and the ability to adapt to specific environmental conditions.

FIGURE 31
THE AQUERT SOIL PROFILE AND LANDSCAPE

The Landscape of Epiaquert

This soil is formed in fine-textured lacustrine deposits that cover river valley plains in Southern Idaho. The soils in this river valley are subject to intensive rainfall. The soil remains waterlogged for less than 45 consecutive days throughout the year, primarily in the spring season. The area has a dry climate with an annual rainfall of 400 mm.

The Profile of Xeric Epiaquert



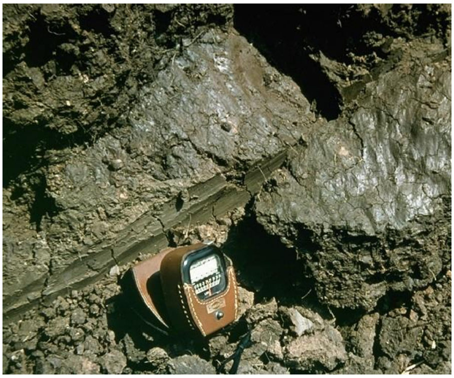
Boulder Lake soil is found in smooth and flat valley plains and lake plains formed by lacustrine deposits. After a period of time, these dust particles weathered into clay, resulting in clay accumulation in the soil profile. Despite an average annual rainfall of only about 350 mm, this soil undergoes short-term waterlogging due to surface runoff from higher plains.

FIGURE 32
THE PHENOMENON OF VERTISOLS

The Cracks of Vertisols

The expansive capacity of Vertisols creates large cracks in the soil. These cracks can be quite wide and can pose a hazard to animals. Materials from the surface accumulate in these cracks during the dry season and are engulfed by the soil during the rainy season, resulting in in-situ mixing in Vertisols.

Slickenside as the Features of Vertisols



Slickensides, which are glossy surfaces, create grooves on the soil's inner surface, forming slickenside planes within the soil. These slickenside planes result from the expanding and shrinking activity of the smectite clay minerals in response to wet and dry cycles. When wet, the soil volume increases, and it decreases when dry. Slickensides form along the inner slickenside planes as soil aggregates move to each other due to changes in volume.

Cracks Wall in Vertisols

Vertisols show typical technical issues due to their high linear extensibility. Special design is required to prevent damage to soil and road structures.

Gilgai relief in the Vertisol landscape.

This photo shows the micro-topography of "gilgai," which is associated with Vertisols. Small mounds and depressions develop as a result of the continuous expansion and contraction of the soil due to the high percentage of clay content that swells and shrinks.

6.2. THE GLOBAL DISTRIBUTION OF VERTISOLS

Vertisols are a unique soil type with a distinctive global distribution. They are primarily found in regions with specific climatic and geomorphic conditions that facilitate their formation. These soils are widely distributed across different continents and occupy about 3.3% of the Earth's land area. Vertisols are predominantly found in semi-arid to subhumid climates where there is a distinct dry and wet season pattern.

One of the significant regions with a notable distribution of Vertisols is the Indian subcontinent, particularly in India, Pakistan, and Bangladesh. These countries have extensive areas covered by Vertisols, often known as "black cotton soils." In Africa, Vertisols are prominent in countries like Sudan, Nigeria, and Ethiopia. These regions experience alternating wet and dry seasons, which contribute to the characteristic cracking behavior of Vertisols.

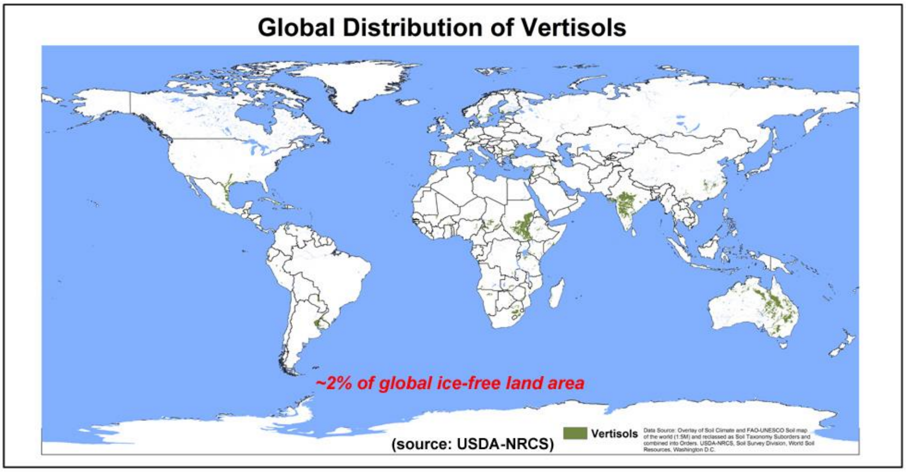


Figure 33. The Global Distribution of Vertisols

In North America, Vertisols can be found in the southern United States, particularly in states like Texas, Mississippi, and Louisiana. These soils are associated with floodplains and low-lying areas that receive periodic heavy rainfall. In South America, Vertisols are present in countries such as Argentina, Brazil, and Venezuela, often occurring in regions with a tropical wet-dry climate.

Australia also features a significant distribution of Vertisols, particularly in its northeastern and southeastern regions. The "cracking clays" in Australia are well-known for their unique shrink-swell properties, forming deep cracks during dry seasons and swelling when wet. Overall, Vertisols play a crucial role in various agricultural practices and land use activities across these diverse regions, influencing the livelihoods of many communities.

CHAPTER VII
ANDISOLS

Andisols are soils formed from volcanic ash or other volcanic materials. These soils are distinguished by their non-crystalline colloid content, such as allophane, imogolite, and ferrihydrite. As a result, Andisols exhibit unique physicochemical properties known as andic properties, including high water-holding capacity and the ability to strongly bind phosphorus in large amounts (rendering it unavailable to plants). Andisols are also known as Andosols in other soil classification systems.

Andisols, a distinct soil order, are characterized by their formation from volcanic ash and other volcanic materials. These soils are rich in unique properties that set them apart from other soil types. The defining feature of Andisols is their abundant non-crystalline colloids, which include substances like allophane, imogolite, and ferrihydrite. These colloids contribute to the exceptional fertility and water-holding capacity of Andisols, making them crucial for agricultural productivity.

One of the remarkable aspects of Andisols is their andic properties, which encompass both physical and chemical attributes. These properties include high cation-exchange capacity, allowing Andisols to hold onto essential nutrients and making them valuable for sustaining plant growth. Their unique capacity to bind phosphorus and other nutrients leads to challenges in nutrient availability for plants, but with proper management, they can be highly productive soils.

Globally, Andisols cover only about 1% of the Earth's land area. They are most prevalent in regions with recent volcanic activity or volcanic parent materials. Due to their fertile nature, Andisols are often used for agricultural purposes, particularly for the cultivation of crops such as coffee, tea, fruits, and vegetables. In some areas, Andisols have been transformed into productive farmland through proper management practices that harness their fertility.

In the United States, Andisols are found in the Pacific Northwest, including states like Oregon and Washington. They contribute to the productivity of forests and agriculture in these regions. In Indonesia, Andisols are distributed across various islands, including Sumatra, Java, and Maluku. These soils support important agricultural activities and contribute to the country's food security.

Andisols have a critical role to play in sustainable agriculture and land management. While their unique properties can present challenges, such as nutrient immobilization, they offer great potential for enhancing soil fertility and productivity through careful management practices. Their distribution in volcanic regions around the world highlights the fascinating geological processes that shape soil formation and its impact on ecosystems and agriculture.

Globally, Andisols have one of the smallest distributions among soil orders, covering only about 1% of the Earth's land area. They encompass approximately 1.7% of the land area in the United States, including productive forests in the Pacific Northwest. In Indonesia, Andisols cover around 5.39 million hectares or 2.9% of the available land, with distribution in North Sumatra (1.06 million ha), East Java (0.73 million ha), West Java (0.50 million ha), Central Java (0.45 million ha), and the Maluku Islands (0.32 million ha).

Andisols are a unique type of soil that is formed from volcanic ash and are characterized by their high fertility and ability to retain nutrients. They are found in volcanic regions around the world and are known for their high organic matter content (Panichini et al., 2012). The distribution of carbon in Andisols can vary depending on land use and management practices. A study by Panichini et al. (2012) investigated the carbon distribution in top- and subsoil horizons of two contrasting Andisols under pasture or forest. The results showed that land use significantly influenced the carbon content and distribution in these soils, with higher carbon concentrations found in the forested areas compared to the pasture areas (Panichini et al., 2012).

The high fertility of Andisols is attributed to their unique mineralogy and physical properties. Andisols have a high cation exchange capacity, which allows them to retain and release nutrients to plants as needed. This, combined with their high water-holding capacity, makes Andisols highly suitable for agricultural use (Panichini *et al*., 2012). However, the high anion retention capacity of Andisols can also pose challenges for nutrient management. The low efficiency of phosphate and molybdate fertilizers in these soils means that farmers may need to apply higher amounts of these fertilizers to achieve desired crop yields (Panichini *et al*., 2012).

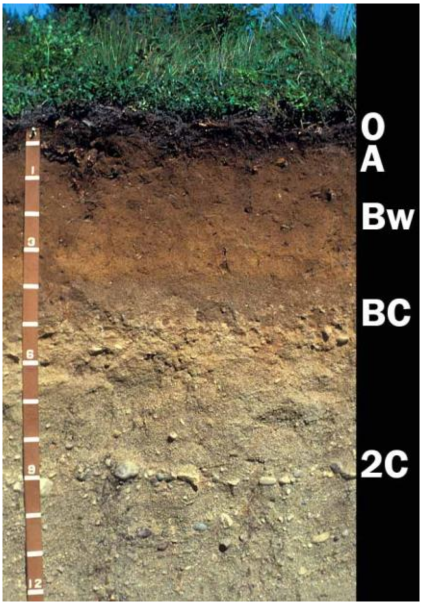


Figure 34. The Profile of Andisols

The distribution of soil organic matter (SOM) in Andisols is an area of ongoing research and uncertainty. While Andisols are known for their high organic matter content, the mechanisms and factors that explain the distribution of SOM through soil profiles are not well understood. Further research is needed to better understand the dynamics of carbon distribution in Andisols and how it is influenced by land use, management practices, and other factors.

In addition to their agricultural importance, Andisols also play a crucial role in carbon sequestration and climate regulation. The high organic matter content in these soils allows them to store significant amounts of carbon, helping to mitigate greenhouse gas emissions and combat climate change. Understanding the factors that influence carbon distribution in Andisols can contribute to more effective carbon sequestration strategies and sustainable land management practices (Panichini *et al.,* 2012).

7.1. ANDISOL SUBORDER CLASSIFICATION

Andisols are classified into eight suborders: AquandS, GelandS, CryandS, TorrandS, Xerands, Vitrands, Ustands, and Udands. These suborders represent variations in the moisture regimes and other specific characteristics of Andisols across different regions and landscapes. The unique properties of Andisols make them valuable for various agricultural and forestry activities, especially in areas where their water-holding capacity and nutrient-binding capabilities play a significant role.

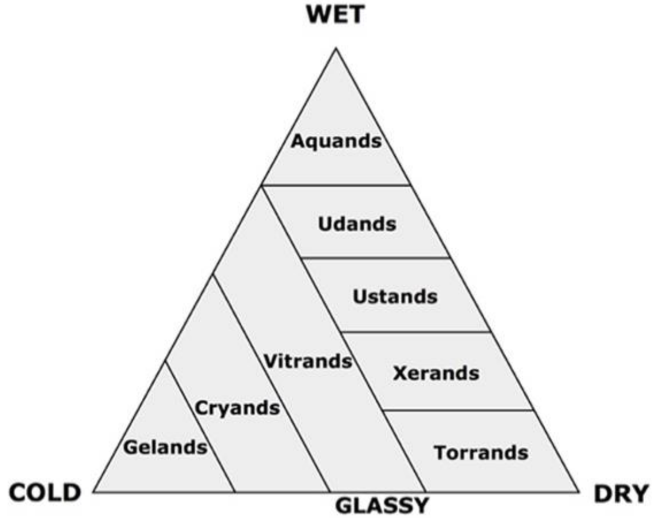


Figure 35. Suborder Diagram of Andisols

Description:

Aquands	-	Andisols with a water table at or near the surface for much of the year
Gelands	-	Annisols of very cold climates (mean annual soil temperature <0°C)
Cryands	-	Andisols of cold climate
Torrands	-	Andisols of very dry climates
Xerands	-	Temperate Andisols with very dry summers and moist winters
Vitrands	-	Relatively young Andisols that are coarse-textured and dominated by glass
Ustands	-	Andisols of semiarid and subhumid climates
Udands	-	Andisols of humid climates

Aquand Suborder

The Aquand suborder is a distinctive classification within the Andisol soil order, characterized by its unique hydrological characteristics and formation processes. Aquands are known for their strong association with water dynamics, making them a vital component of landscapes where water movement and management are crucial.

Aquand soils are often found in regions with high water tables, such as wetlands, floodplains, and areas with poor drainage. They exhibit a high degree of saturation, which leads to the development of reduced conditions and waterlogged profiles. These conditions inhibit the breakdown of organic matter, resulting in the accumulation of organic materials in the soil profile. The presence of a shallow water table or waterlogged conditions for a significant portion of the year distinguishes Aquands from other Andisol suborders. This persistent saturation can impact soil properties and nutrient cycling, influencing the types of vegetation that can thrive in these areas. While Aquands have challenges related to aeration and nutrient availability, they also contribute to the overall hydrological function of landscapes by storing and releasing water during wet and dry periods.

Due to their waterlogged nature, Aquand soils often serve as important habitats for various aquatic and semi-aquatic plant species, as well as diverse aquatic fauna. These areas can support unique ecosystems that contribute to biodiversity and provide valuable ecosystem services such as water filtration and flood regulation. In terms of land use, Aquand soils are often utilized for wetland conservation, wildlife habitats, and even agricultural practices in some cases. Effective management strategies are essential to balance the conservation of these water-logged environments with sustainable land use practices. Overall, the Aquand suborder highlights the dynamic interplay between water and soil in shaping ecosystems and landscapes.

Geland Suborder

The Geland suborder is a distinctive classification within the Andisol soil order, known for its occurrence in cold and mountainous regions where glacier activity has played a significant role in soil formation. These soils are typically found in areas with a history of glaciation and are characterized by their unique properties and development processes. Geland soils are formed from glacial deposits, including moraines, outwash plains, and other materials left behind by retreating glaciers. The parent materials of Geland soils often consist of a mixture of rock fragments, sand, silt, and clay. These deposits are often layered and unsorted, reflecting the processes of glacial deposition.

One of the defining features of Geland soils is their presence in high-elevation and cold environments. The suborder name itself, "Geland," is derived from the Dutch word for "frozen." The cold climate limits the rate of soil development, and the presence of permafrost—permanently frozen ground—can further influence soil properties and processes. Geland soils exhibit characteristics influenced by their glacial origin, including a wide range of particle sizes and mineral compositions. The variability in parent material and deposition processes contributes to the diversity of Geland soil properties across different regions.

Due to their cold and often high-altitude locations, Geland soils have limited agricultural potential. However, they play a crucial role in alpine and subarctic ecosystems, supporting unique plant and animal communities adapted to harsh conditions. The preservation and conservation of Geland soils are essential for maintaining the integrity of these fragile ecosystems and understanding the geological history of glaciated areas.

Cryand Suborder

The Cryand suborder is a classification within the Andisol soil order, known for its occurrence in cold regions where permafrost, or permanently frozen ground, plays a crucial role in soil development. These soils are found in environments where the presence of permafrost affects soil properties, water movement, and overall ecosystem dynamics. Cryand soils are characterized by their development under the influence of freeze-thaw cycles caused by the presence of permafrost. The suborder name, "Cryand," is derived from the Greek word "kryos," meaning cold, reflecting the dominant climatic condition in which these soils form.

The freezing and thawing of Cryand soils lead to the formation of distinctive features such as ice wedges, frost boils, and polygonal patterns on the soil surface. These patterns are a result of the expansion and contraction of water as it freezes and thaws, creating dynamic changes in the soil structure and landscape. Cryand soils are often rich in organic matter, which accumulates due to the cold climate's slow decomposition rates. The presence of permafrost can impede water drainage, leading to the formation of waterlogged areas that promote the accumulation of organic materials.

Due to the harsh conditions of cold environments and permafrost presence, Cryand soils have limited agricultural potential. However, they play a crucial role in supporting unique ecosystems adapted to cold climates. These soils provide a habitat for cold-adapted vegetation and wildlife and contribute to the overall ecological balance of cold regions.

Torrand Suborder

The Torrand suborder is a classification within the Andisol soil order, representing soils that form in volcanic ash deposits under tropical or subtropical climates. These soils are found in regions with active or past volcanic activity, where the accumulation of volcanic ash has played a significant role in their formation. The name "Torrand" is derived from the Latin word "torrens," meaning torrent or stream, highlighting the influence of water on the development of these soils. Torrand soils are characterized by their susceptibility to erosion and rapid water movement due to their porous and loosely structured nature.

One of the defining features of Torrand soils is their rich content of volcanic glass and minerals derived from volcanic ash. These minerals contribute to the unique properties of these soils, such as high cation exchange capacity (CEC) and fertility. The volcanic ash also provides a fine texture to Torrand soils, making them capable of holding water and nutrients, which is especially important in regions with seasonal droughts. Torrand soils often display a distinct layering of volcanic ash deposits, which can vary in thickness and mineral composition. This layering can result in variations in soil properties within a profile, affecting water retention, nutrient availability, and root penetration.

Agriculturally, Torrand soils have significant potential due to their inherent fertility and water-holding capacity. They are often used for the cultivation of various crops, especially in tropical regions with favorable climates. However, their susceptibility to erosion and rapid water movement necessitates proper land management practices to prevent soil degradation.

Xerand Suborder

The Xerand suborder is a classification within the Andisol soil order, representing soils that form in volcanic ash deposits under arid or semiarid climates. These soils are typically found in regions with volcanic activity and limited rainfall, where the combination of volcanic ash and dry conditions contributes to their unique properties. The name "Xerand" is derived from the Greek word "xeros," meaning dry, reflecting the arid nature of the environments where these soils develop. Xerand soils are adapted to low moisture availability, and their formation is influenced by the interplay between volcanic materials, climate, and topography.

Xerand soils often exhibit well-developed horizons with mineral accumulation and weathering features. They contain a mixture of volcanic glass and minerals, and their texture can range from sandy to clayey, depending on the specific mineral composition and particle sizes present in the volcanic ash deposits. One of the key features of Xerand soils is their ability to store and release nutrients efficiently. The volcanic minerals present in these soils have a high cation exchange capacity (CEC), allowing them to retain essential nutrients even in dry conditions. This nutrient retention capability is essential for supporting plant growth in arid environments.

Agriculturally, Xerand soils can be challenging to manage due to their limited water availability. However, their inherent fertility and nutrient-holding capacity make them suitable for certain types of crops, especially when combined with irrigation practices. Effective irrigation management and soil conservation techniques are crucial for maximizing agricultural productivity while minimizing the risk of soil erosion.

Vitrand Suborder

The Vitrand suborder is a classification within the Andisol soil order, representing soils that form in volcanic ash deposits under temperate or cold climates. These soils are found in regions with volcanic activity and relatively cooler temperatures, where the interactions between volcanic materials, climate, and landscape play a role in their development. The term "Vitrand" is derived from the Latin words "vitreus," meaning glass-like, and "terra," meaning earth or soil. This reflects the presence of volcanic glass fragments in these soils, which contribute to their distinct properties. Vitrand soils are typically characterized by a high content of volcanic glass particles, resulting in unique texture and mineral composition.

Vitrand soils often exhibit well-defined horizons and distinct soil properties. The volcanic glass fragments present in these soils can be amorphous or crystalline and are usually resistant to weathering, contributing to the soils' mineralogical diversity. These soils can have varying textures, including sandy, loamy, or clayey, depending on the size distribution of the volcanic glass and mineral particles. One of the significant features of Vitrand soils is their ability to retain moisture and nutrients. The volcanic glass fragments have a high surface area, which enhances their capacity to hold water and essential nutrients, supporting plant growth even in cooler climates. Additionally, the unique mineralogy of Vitrand soils can contribute to their ability to retain nutrients like phosphorus.

Agriculturally, Vitrand soils can provide fertile grounds for crop cultivation, particularly in cooler climates. The presence of volcanic glass fragments and minerals can enhance soil fertility and provide a favorable environment for root development. Proper soil management practices, such as appropriate irrigation and nutrient management, are essential to harness the agricultural potential of Vitrand soils.

Ustand Suborder

The Ustand suborder is a classification within the Andisol soil order, representing soils that form in volcanic ash deposits under dry or semi-arid climates. These soils are found in regions with volcanic activity and relatively low precipitation, where the interplay between volcanic materials, climate, and landscape influences their development. The term "Ustand" reflects the nature of these soils as occurring in areas with limited moisture availability. Ustand soils are typically characterized by their ability to retain water in arid environments due to their unique texture and mineral composition. These soils often have well-defined horizons and properties that allow them to effectively store and distribute water.

Ustand soils generally have a porous structure with relatively high permeability, allowing them to absorb and hold water efficiently. The volcanic glass fragments present in these soils contribute to their water-holding capacity, making them well-suited for retaining moisture in dry conditions. Despite the low precipitation in the regions where Ustand soils are found, these soils can provide a reliable source of water for vegetation.

One of the challenges of Ustand soils is their potential for water erosion. The permeable nature of these soils can lead to rapid water infiltration, which may result in soil erosion during heavy rainfall events. To mitigate this issue, proper land management practices such as contour farming and vegetation cover are essential to prevent soil loss.

Udand Suborder

The Udand suborder is a classification within the Andisol soil order, representing soils that develop in volcanic ash deposits under humid and wet conditions. These soils are commonly found in regions with high precipitation and volcanic activity, where the combination of volcanic materials and ample moisture influences their formation. The name "Udand" highlights the significant influence of moisture on these soils. Udand soils are characterized by their high water-holding capacity and the ability to retain moisture even in humid environments. The volcanic materials in these soils, such as volcanic glass and minerals, contribute to their unique properties and water-retention capabilities.

Udand soils often have distinct horizons that reflect the accumulation of organic matter, minerals, and clay particles. This horizon development results from the interaction between volcanic ash and the abundant moisture present in these regions. These soils can exhibit well-drained properties while also retaining enough moisture to support vegetation growth. One of the key features of Udand soils is their fertility. The volcanic materials and their interaction with moisture lead to the accumulation of nutrients in these soils, making them highly suitable for agricultural activities. Their fertility makes Udand soils valuable for various crops and plantations, including fruits, vegetables, and crops that require nutrient-rich soils.

FIGURE 36

THE UDAND SOIL PROFILE AND LANDSCAPE

The Landscape of Melanudand

Melanudand is found on the upper slopes of Mount Turrialba in the highlands of Costa Rica. This soil has a high organic matter content with a high water-holding capacity.

The Profile of Melanudand

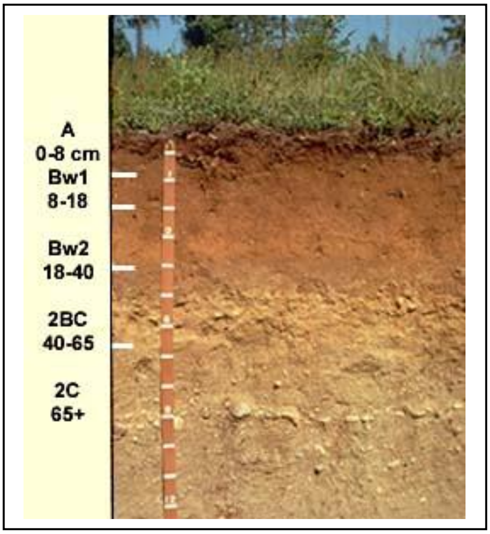
This soil is formed on volcanic ash layers from the volcano. The dark surface is a characteristic feature indicating the melanic epipedon. This horizon contains 16.4% organic matter. Soil water content at 1500 kPa ranges from 147% in horizon A1 to 226% in horizon Bw.

FIGURE 37
THE XERAND SOIL PROFILE AND LANDSCAPE

The Landscape of Vitrixerand

This area resulted from repeated floods of melted ice from Lake Missoula over 13,000 years ago. The soil formed from these catastrophic flood deposits. Periodic volcanic ash falls in the area mix into the upper profile. The largest ash fall occurred 7,700 years ago from Mount Mazama. The soil is used for timber production, grazing, and irrigated agricultural products.

The Profile of Typic Vitrixerand



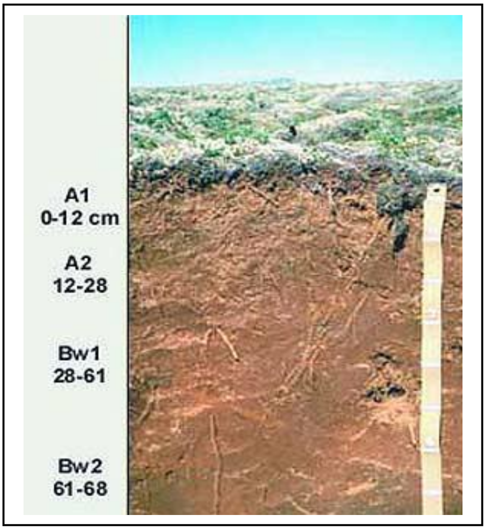
This soil profile is formed from two-parent materials and is a characteristic of many Andisols in northern Idaho, eastern Washington, and western Montana. At a depth of 35 to 60 cm in the profile, there is a 60% content of volcanic ash, mainly originating from the eruption of Mount Mazama (now Crater Lake) in southwestern Oregon, about 7,700 years ago. The lower part of the profile is formed from glacial deposits from the Glacial Missoula Lake, through devastating floods that occurred during the Pleistocene era. In the WRB Classification System, this soil is classified as Vitric Andosol.

FIGURE 37
THE CRYAND SOIL PROFILE AND LANDSCAPE

The Landscape of Cryand

Most of the highland ice landscapes naturally consist of deep Andisols that lie atop glacial plains. However, excessive grazing practices and the vulnerability of these Andisols to wind erosion have occurred in the landscape depicted in the photo above. In the foreground, the glacial rock plain has been exposed due to the erosion of the Andisol cover, leading to a desertification process. Despite an average annual rainfall of approximately 1100 mm, only minimal vegetation can survive on the glacial plains.

The Profile of Typic Haplocryand



This Andisol, known as the Thingvallasveit pedon, has formed from volcanic ash and eolian materials around Thingvellir National Park in southwestern Iceland. The upper part, with a thickness of 60 cm, contains 70-80 g/kg of organic carbon and exhibits weak horizonation. The soil has a weak structure, and its volcanic ash particles are predominantly dust and sand-sized, making it highly susceptible to wind erosion.

7.2. THE GLOBAL DISTRIBUTION OF ANDISOLS

Andisols are a unique soil order with a global distribution that covers approximately 1% of the Earth's land area. These soils are characterized by their formation from volcanic ash and other volcanic materials, which contribute to their distinct properties. Andisols are found in regions with a history of volcanic activity, and their distribution is widespread, spanning various continents.

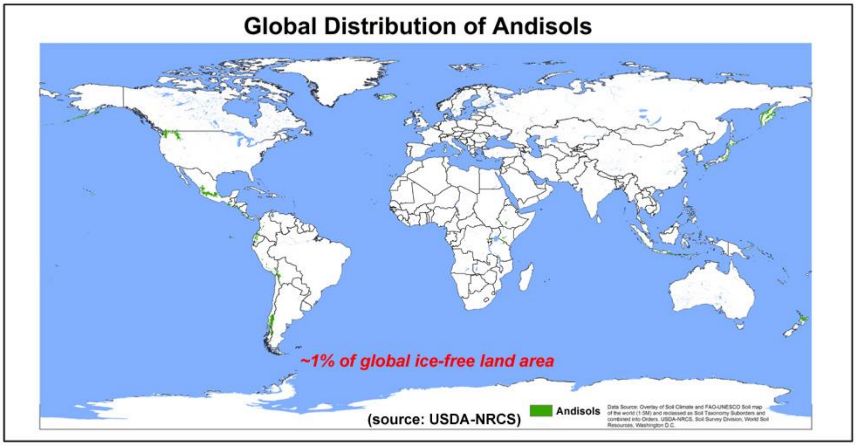


Figure 38. The Global Distribution of Andisols

In North America, Andisols can be found in areas like the Pacific Northwest of the United States, particularly in states like Washington, Oregon, and parts of Idaho. These regions have experienced past volcanic eruptions that have contributed to the formation of Andisols. These soils are known for their exceptional water-holding capacity, making them valuable for agriculture in areas with distinct wet and dry seasons.

In South America, Andisols are prevalent in volcanic regions of countries such as Chile, Ecuador, and Colombia. The volcanic activity in the Andes Mountains has played a significant role in the development of Andisols in this part of the world. These soils are vital for agriculture in the Andean highlands, where crops like potatoes and quinoa thrive.

In Asia, Andisols can be found in countries like Japan, Indonesia, and the Philippines, where volcanic islands have created favorable conditions for their formation. In Japan, for example, Andisols are known as "Ando soils" and are prized for their fertility. They are used for growing a variety of crops, including rice, vegetables, and tea.

In Africa, Andisols are less common but can be found in some volcanic regions, such as the East African Rift. These soils are essential for agriculture in parts of Ethiopia and Kenya, contributing to food production in these areas.

CHAPTER VIII
SPODOSOLS

Spodosols are acidic soils characterized by a subsurface horizon that accumulates humus complexed with aluminum (Al) and iron (Fe). These soils typically form from coarse-textured parent material and have a bright E horizon above a reddish-brown spodic horizon. The formation process of this horizon is referred to as podsolization. Spodosols are often encountered in cold and humid coniferous forests. Spodosols are equivalent to Podzols in other classification systems. Most Spodosols are found in forested regions.

Spodosols are a distinct type of soil found in various regions around the world, characterized by their unique properties and formation processes. These soils are typically associated with cold and humid climates and are often found in coniferous forests. Spodosols exhibit several distinctive features that set them apart from other soil types.

One of the defining characteristics of Spodosols is their acidic nature. These soils have a low pH, which makes them unsuitable for many agricultural purposes without proper amelioration. The acidity is a result of the accumulation of organic matter and complex compounds with aluminum and iron in their subsurface horizons. This accumulation forms a distinctive horizon known as the spodic horizon, which is typically reddish-brown.

Spodosols are formed through a process called podsolization. This process occurs as water leaches through the soil, carrying organic material and minerals downward. In the upper horizons, known as the E horizon, the leaching of minerals results in a lighter coloration. Below this, in the spodic horizon, the accumulation of organic matter and metal complexes creates the distinctive reddish-brown color and acidic conditions.

These soils are widespread globally, covering approximately 4% of the Earth's land area. In the United States, they occupy about 3.5% of the total land area. Given their natural infertility due to acidity and other factors, Spodosols often require liming and other soil amendments to become suitable for agriculture. However, they are crucial components of forest ecosystems, especially in colder, northern regions.

In the world, these soils cover approximately 4% of the land area. In the United States, they account for about 3.5% of the total land area. Due to their natural infertility, Spodosols require liming to become fertile agricultural land. Spodosols in Indonesia cover only 1.1% of the country's land area. The chemical properties of these soils are characterized by their acidity and poor nutrient content. Their coarse texture results in low nutrient and water retention capabilities, making them susceptible to drought. In Indonesia, Spodosols can be found from coastal areas to highlands exceeding 1,500 meters above sea level, with total annual average rainfall ranging from 1,000 to over 3,000 mm. Based on the Soil Resource Exploration Atlas of Indonesia at a 1:1,000,000 scale (Puslittanak, 2000), Spodosols are primarily found in Sumatra, Kalimantan, Sulawesi, and Papua. In regions with arid climates, such as West Nusa Tenggara and East Nusa Tenggara, these soils are not present.

Spodosol's limited distribution in Indonesia is attributed to its specific environmental requirements, including cold and humid conditions. These soils are less common in regions with warmer and drier climates. Their acidic nature and low nutrient content can pose challenges for agriculture, requiring careful management practices if they are to be used for farming. Nonetheless, Spodosols play a role in Indonesia's diverse soil landscape, showcasing the country's rich soil diversity.

Spodosols are soil types found in various coastal environments, including the Barreiras Formation and Restingas in Brazil (Oliveira *et al.*, 2010). The genesis of Spodosols in these areas is influenced by the pre-weathered sediments of the Barreiras Formation, which leads to the destruction of the clay fraction and the migration of its constituent elements through sandy horizons (Silva *et al.*, 2019). This results in the accumulation of these elements in the clayey subsurface horizon, giving rise to the characteristic spodic B horizon (Bh, Bs, or Bhs) overlying a textural B horizon (Bt) (Silva *et al.*, 2019).

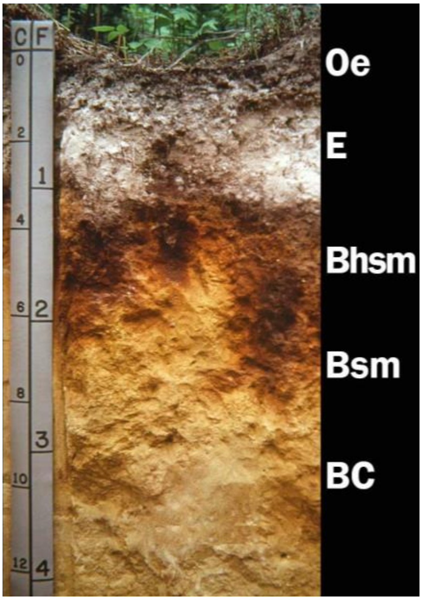


Figure 39. The Profile of Spodosols

Spodosols are typically formed under forest vegetation, and studies have focused on their formation and characteristics in forested areas (Yli-Halla *et al.*, 2008). However, there is a lack of comprehensive studies on cultivated Spodosols (Yli-Halla *et al.*, 2008). In Finland, for example, Spodosols are characterized by light-colored eluvial horizons with bleached, uncoated sand grains and a dark, reddish-colored illuvial horizon with accumulated organic matter and Al oxides with or without Fe oxides (Yli-Halla *et al.*, 2008).

The characteristics of Spodosols can vary depending on the source material, morphology, and genesis (Oliveira *et al.*, 2010). In the south of Bahia, Brazil, a Spodosol with intermediate characteristics between Ultisol and Argilluvic Orthic Humiluvic Spodosol was identified based on the presence of a spodic B horizon overlying a textural B horizon (Silva *et al.*, 2019).

Overall, Spodosols are important soil types found in coastal environments, and their genesis is influenced by factors such as pre-weathered sediments, clay fraction destruction, and migration of constituent elements (Silva *et al*., 2019). Further research is needed to understand the formation and characteristics of cultivated Spodosols in different regions (Yli-Halla *et al*., 2008).

8.1. SPODOSOL SUBORDER CLASSIFICATION

Spodosols are further categorized into five suborders: Aquods, Gelods, Cryods, Humods, and Orthods. Each suborder represents variations in Spodosol properties and is often associated with specific geographic regions and climate conditions. Overall, Spodosols play a significant role in ecological systems and provide insights into the relationship between soils, climate, and vegetation.

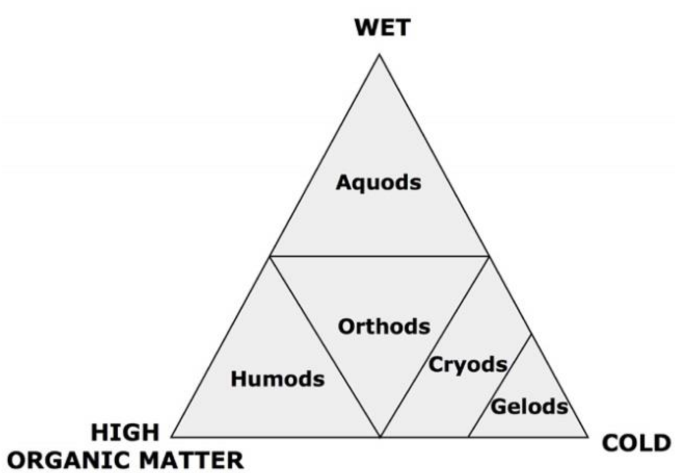


Figure 40. Suborder Diagram of Spodosols

Description:

Aquods	-	Poorly drained Spodosols with a water table at or near the surface for much of the year
Gelods	-	Spodosols of very cold climates (mean annual soil temperature <0°C)
Cryods	-	Spodosols of cold climates

Humods - Well-drained Spodosols that contain relatively large quantities of organic matter

Orthods - Common Spodosols that don't meet the requirements of another suborder

Aquod Suborder

The Aquod Suborder is a significant classification within the larger category of Spodosols, which are acidic soils known for their unique soil horizon development. These soils are characterized by a distinct subsurface horizon enriched with organic matter and aluminum and iron compounds. The term "Aquod" refers to the specific moisture regime exhibited by these soils, emphasizing their high water table or seasonal saturation characteristics.

Aquods typically develop in regions with cold and humid climates, especially in boreal or northern coniferous forest ecosystems. The extensive, cold, and often waterlogged landscapes of these regions contribute to the formation of Aquods. They often occur in low-lying areas and depressions where water accumulates during the wetter seasons.

One of the defining features of Aquods is the presence of a spodic horizon, which is a subsurface horizon characterized by the accumulation of organic matter, iron, and aluminum oxides. This horizon is typically colored brown or reddish-brown and contrasts sharply with the lighter-colored surface horizons. The spodic horizon's formation is closely related to the leaching and translocation of these materials from the upper horizons to the subsurface due to the acidic and waterlogged conditions in which Aquods develop.

Due to their specific moisture and temperature requirements, Aquods are generally not suitable for agricultural purposes. Instead, they are essential components of the ecosystems they inhabit, contributing to the unique vegetation and hydrological characteristics of cold, humid regions. Proper understanding and conservation of these soils are crucial for maintaining the health and sustainability of these delicate ecosystems.

Gelod Suborder

The Gelod Suborder is a notable classification within the Spodosol order, known for its unique soil properties and formation processes. Spodosols are typically found in cold and humid climates, and the Gelod Suborder specifically denotes soils that exhibit particular characteristics within this category.

Gelod Suborder soils are characterized by the presence of a spodic horizon, which is a subsurface horizon enriched with organic matter, iron, and aluminum compounds. This horizon is typically reddish-brown and contrasts sharply with the lighter-colored surface horizons. The formation of the spodic horizon is a distinctive feature of Gelod soils and is associated with the leaching and translocation of these materials from the upper horizons to the subsurface due to the acidic and waterlogged conditions in which these soils develop.

These soils are commonly found in regions with cold and humid climates, such as boreal forests and northern coniferous ecosystems. The cool temperatures and high precipitation levels in these areas create ideal conditions for Gelod Suborder soils to develop. They are often found in low-lying areas and depressions where water accumulates during wet seasons.

Gelod soils are generally not suitable for agriculture due to their specific moisture and temperature requirements, which are better suited for natural ecosystems. Instead, they play a crucial role in these ecosystems, contributing to the unique vegetation and hydrological characteristics of cold, humid regions. Proper conservation and management of Gelod soils are essential for preserving the health and sustainability of these delicate ecosystems. Understanding their properties and formation processes is vital for environmental scientists and land managers working in such regions.

Cryod Suborder

The Cryod Suborder is a distinctive classification within the Spodosol order, characterized by unique soil properties and formation processes that are closely associated with extremely cold climates. These soils are found in polar and subpolar regions, where freezing temperatures and frozen ground are prevalent.

Cryod Suborder soils are known for the presence of a permafrost layer, which is a permanently frozen layer of soil or rock below the surface. This permafrost layer can extend to considerable depths, making it a defining feature of Cryod soils. The presence of permafrost significantly affects the soil's physical and chemical properties. These soils are typically found in high-latitude areas, such as the Arctic and subarctic regions, where temperatures remain below freezing for a significant portion of the year. The extremely cold climate limits biological activity in the soil, leading to the accumulation of organic matter in the upper horizons. This organic matter, combined with iron and aluminum compounds, contributes to the distinctive reddish-brown coloration of the spodic horizon commonly found in Cryod soils.

Cryod soils play a vital role in the ecosystems of polar and subpolar regions. They support unique vegetation adapted to cold and nutrient-poor conditions. The presence of permafrost also influences hydrological processes, including water storage and drainage. Understanding the properties and behavior of Cryod Suborder soils is crucial for researchers and policymakers concerned with the preservation of these fragile, cold-climate ecosystems in the face of climate change and environmental challenges.

Due to the extreme conditions of these regions, Cryod soils are generally unsuitable for agricultural purposes. Their conservation and proper management are essential for maintaining the ecological balance of polar and subpolar environments. As climate change continues to impact these regions, monitoring Cryod soils and their response to warming temperatures becomes increasingly important for assessing the health of these sensitive ecosystems.

Humod Suborder

The Humod Suborder is a classification within the Spodosol order, known for its distinctive soil properties and formation processes. These soils are typically found in regions with cold, humid climates and are characterized by specific horizons and chemical characteristics. One of the defining features of Humod Suborder soils is the presence of a well-developed spodic horizon. This horizon, often referred to as the "E horizon," is characterized by the leaching of minerals and the accumulation of organic matter, resulting in a greyish or whitish appearance. The spodic horizon plays a crucial role in the retention and release of nutrients in the soil.

Humod soils are typically found in cold, humid regions, such as boreal forests and subarctic areas. These climates have cool to cold temperatures and ample precipitation, which influence the soil's properties. The organic matter content in Humod soils is relatively high, making them important for nutrient cycling and supporting vegetation adapted to these conditions. The presence of organic matter in Humod soils helps improve their water-holding capacity, which can be essential in areas with prolonged wet periods. These soils often have good fertility due to the decomposition of organic matter, which releases nutrients into the soil. However, they can be vulnerable to nutrient leaching in areas with excessive rainfall.

Humod Suborder soils are generally not suitable for agriculture due to their cold, humid, and often remote locations. Instead, they play a crucial role in supporting natural ecosystems, particularly boreal forests. Understanding the properties and behavior of Humod soils is essential for land management and conservation efforts in these sensitive cold-climate environments. As climate change continues to affect these regions, monitoring Humod soils becomes increasingly important for assessing the impacts on nutrient cycling and ecosystem health.

Orthod Suborder

The Orthod Suborder is a significant classification within the Spodosol order, and it represents a group of soils with distinct properties and characteristics. These soils are typically found in cold, humid regions, particularly in northern boreal forests, where cold and wet conditions influence their formation.

One of the defining features of the Orthod Suborder is the presence of a well-developed spodic horizon, commonly referred to as the "E horizon." This horizon is characterized by the leaching of minerals and the accumulation of organic matter, resulting in a light-colored layer within the soil profile. The spodic horizon plays a crucial role in the retention and release of nutrients in the soil, influencing the fertility and ecosystem dynamics of these soils. Orthod soils are usually associated with cold and humid climates, where temperatures are consistently low, and precipitation is ample. These conditions influence the properties of the soil, including the accumulation of organic matter. The organic matter content in Orthod soils is relatively high, making them important for nutrient cycling and supporting vegetation adapted to these cold environments.

Due to their cold, humid, and often remote locations, Orthod soils are not typically suitable for agriculture. Instead, they play a vital role in supporting natural ecosystems, particularly in boreal forests. These soils contribute to the health and sustainability of these ecosystems by providing essential nutrients and regulating water availability.

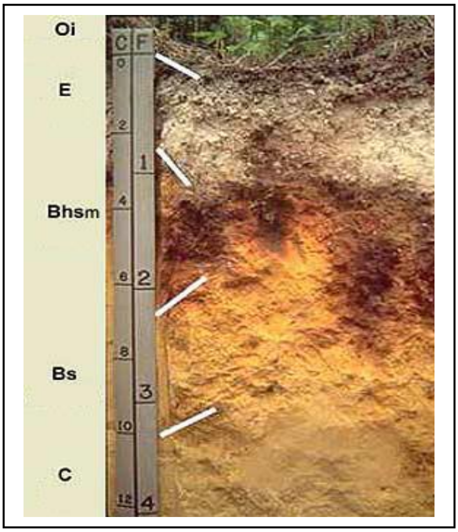
Understanding the properties and behavior of Orthod Suborder soils is crucial for land management and conservation efforts in cold, humid regions. As climate change continues to impact these areas, monitoring Orthod soils becomes increasingly important for assessing the potential effects on nutrient cycling, soil health, and overall ecosystem resilience.

FIGURE 41
THE ORTHOD SOIL PROFILE AND LANDSCAPE

Landscape of Durorthod

These soils are found in glacial outwash plains. Land use is limited due to the naturally low fertility of the soil. Most open lands are not sustainable for use; these soils do not support the growth of woody plants, pine, and fir.

Profile of Typic Durorthod



This soil is found in hilly and sandy glacial outwash plains in southern Michigan and New York. The average annual rainfall ranges from 660-830 mm, and it has an average annual temperature between 5-7°C. This soil has a very distinct spodic horizon, which is strongly cemented as ortstein. As shown in the adjacent image, the irregular topography is indicative of the boundaries between the E/Bhsm and Bhsm/Bsm horizons.

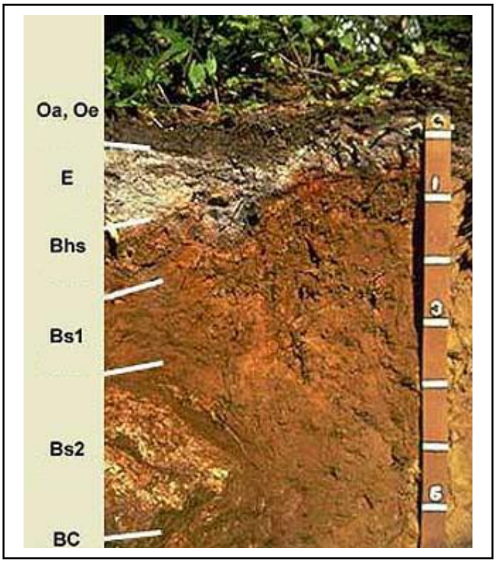
FIGURE 42

THE CRYOD SOIL PROFILE AND LANDSCAPE

Landscape of Haplocryod

Volcanic ash above glacial deposits along the Selkirk Mountains in northern Idaho. Andisols are found at lower elevations, while Spodosols dominate the higher elevations. In this area, they are associated with the vegetation community of fir forests (Abies lasiocarpa), where podsolization (the redistribution of organic complexes with Al/Fe) occurs extensively.

Profile of Andic Haplocryod



This soil is found at an elevation of approximately 6000 feet in the Selkirk Mountains in northern Idaho and is associated with fir forests. The upper part of this soil consists mainly of volcanic ash from the eruption of Mount Mazama and is underlain by very coarse-textured glacial till derived from granitic rocks of the Kaniksu batholith. Horizons E, Bhs, and Bs1 have a dusty clay texture and consist of 25-30% volcanic glass. Horizon E has a pH of 3.7, while horizons Bhs and Bs1 have a phosphorus retention level of 95-96%.

8.2. THE GLOBAL DISTRIBUTION OF SPODOSOLS

Spodosols, a unique and distinctive soil order, have a global distribution that is primarily influenced by specific environmental conditions and climatic characteristics.

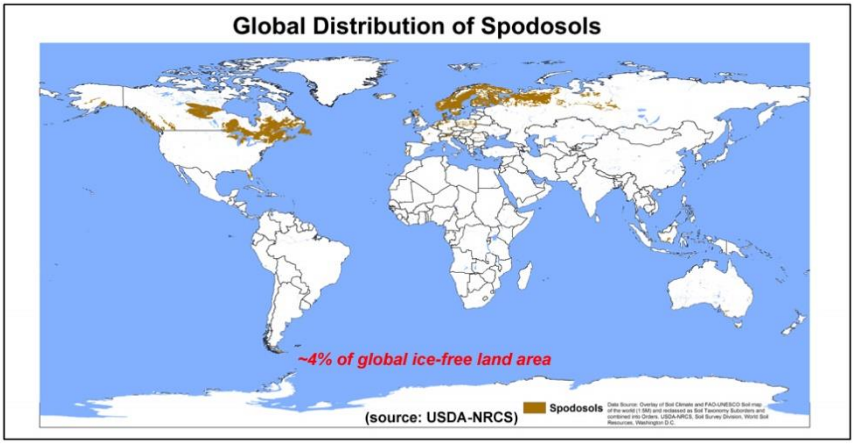


Figure 43. The Global Distribution of Spodosols

Spodosols are notably widespread in North America, particularly in the northern regions of the United States and Canada. In the United States, they are commonly found in states such as Michigan, Wisconsin, and Minnesota. The cold and humid conditions in these regions, coupled with the presence of coniferous forests, create ideal environments for the formation of Spodosols. In Canada, provinces like Ontario, Quebec, and British Columbia also feature significant Spodosol occurrences, often associated with boreal forests.

Northern European countries, including Sweden, Finland, Norway, and Russia, host extensive areas with Spodosols. These soils are intricately linked to the vast boreal forests and heathlands of the region. Russia, with its expansive Siberian territory, has a substantial presence of Spodosols, particularly in its northern areas.

Spodosols can be found in parts of northern Asia, especially in Russia's Siberian regions. Similar to Europe, they are often associated with the taiga and boreal forests that dominate these areas. The cold and humid climate of these regions plays a vital role in the formation of Spodosols.

The Scandinavian countries of Sweden and Finland are renowned for their significant Spodosol occurrences, primarily in the northern regions. These soils are intricately linked with the dense coniferous forests characteristic of the subarctic climate in these countries.

High-Altitude and Mountainous Regions: Spodosols are also present in high-altitude mountainous areas across the globe. These regions, characterized by cold temperatures and often covered in coniferous forests, provide the ideal conditions for Spodosol development. In such areas, Spodosols contribute to the unique ecosystems and vegetation patterns.

Spodosols are distinguished by their characteristic spodic horizon, which is a distinct layer marked by the accumulation of organic matter and metal oxides. This horizon imparts acidity to the soil and influences its fertility. While Spodosols are typically less suitable for agriculture due to their acidic nature, they play crucial roles in natural ecosystems and forestry. The global distribution of Spodosols is closely linked to cold, humid climates and the presence of coniferous vegetation, making them a fascinating subject of study in soil science and land management.

CHAPTER IX
ULTISOLS

Ultisols, also known as Ultisol, are a prominent soil order characterized by advanced weathering, acidity, and relatively low fertility. They are commonly found in humid tropical regions and humid temperate areas, particularly in mature and stable landscapes. Ultisols have undergone intensive weathering of primary minerals, resulting in the leaching of calcium (Ca), magnesium (Mg), and potassium (K) ions from the soil. These soils often exhibit a subsoil horizon with clay accumulation and are frequently tinged with yellowish or reddish colors due to iron oxide presence. For example, the red clay soils in the southern United States are a classic example of Ultisols.

Ultisols are typically acidic and have a relatively low capacity to retain essential nutrients. The leaching process in Ultisols washes away important cations, making them less fertile. They often require soil amendments and fertilizers to support agriculture. Despite their challenges, Ultisols can be agriculturally productive when properly managed, and they support various land uses, including forestry and pasture.

These soils are part of the larger category of Oxisols in the World Reference Base for Soil Resources (WRB) classification system. However, in the United States Soil Taxonomy system, they are classified as Ultisols. Ultisols are further subdivided into different suborders, each with unique characteristics based on factors like climate, parent material, and vegetation cover. Understanding the properties of Ultisols is crucial for effective land management and sustainable agriculture in regions where they predominate.

Ultisols cover approximately 8.1% of the Earth's land area and support human populations worldwide. These soils dominate in the southern United States, accounting for approximately 9.2% of the total land area in the United States.

Ultisols are one of the extensive soil orders, covering 25% of Indonesia's land area, approximately 45 million hectares. Ultisols in Indonesia constitute the largest part of upland areas, covering approximately 45,794,000 hectares. These soils are distributed across various regions, including Kalimantan (21,938,000 ha), Sumatra (9,469,000 ha), Maluku and Papua (8,859,000 ha), Sulawesi (4,303,000 ha), Java (1,172,000 ha), and the Lesser Sunda Islands (53,000 ha). Ultisols can be found across different types of terrain, ranging from flatlands to mountainous regions (Subagyo et al., 2004).

According to Radjagukguk (1983), there are approximately 1,023 million hectares of Ultisols in West Sumatra, accounting for about 6.1% of the total Ultisol land area in Indonesia (LPT, 1979). Considering their extensive coverage and distribution, Ultisols have significant potential for expanding and enhancing agricultural production in Indonesia.

Ultisols are important in agricultural systems, but their productivity can be influenced by factors such as soil management, climate, and vegetation cover. Proper management practices are essential to maximize the agricultural potential of Ultisols while minimizing soil degradation and environmental impacts.

Ultisols are characterized as low-fertility soils with high acidity and aluminum exchangeability (Purwanto et al., 2020). They have a low cation exchange capacity (CEC), base saturation (BS), and soil pH (Purwanto et al., 2020). Ultisols are considered old soils and require management strategies such as balanced fertilization and liming for agricultural purposes (Purwanto et al., 2020).

In terms of agricultural productivity, Ultisols are more responsive to farmyard manure (FYM) during the dry season due to higher temperatures and relatively dry soil conditions, which enhance the mineralization of organic matter into plant-available nutrients (Achieng et al., 2010). However, the addition of nitrogen (N) fertilizer did not increase yield in Ultisols, possibly due to a decline in soil pH and inefficient utilization of applied resources (Achieng et al., 2010).

Comparing Ultisols to Alfisols, which are another soil type, it was found that during the wet season, all treatments in Alfisols resulted in nearly double the grain yield compared to Ultisols (Achieng et al., 2010). However, in both soil types, the combination of FYM and 30 kg N ha-1 provided maize grain yield equivalent to that of N, NP, and NPK treatments (Achieng et al., 2010). This suggests that the use of FYM can be a cost-effective option for maize production on both Ultisols and Alfisols, especially for smallholder farmers who may not be able to afford large amounts of fertilizer and liming (Achieng et al., 2010).

Furthermore, in terms of plant population, height, cob number, stover, grain yield, and 100-seed weight, FYM was not significantly different from other inorganic fertilizer treatments in both Ultisols and Alfisols (Achieng et al., 2010). However, during the dry season, Ultisols had a higher plant population, cob number, and grain yield compared to Alfisols (Achieng et al., 2010).

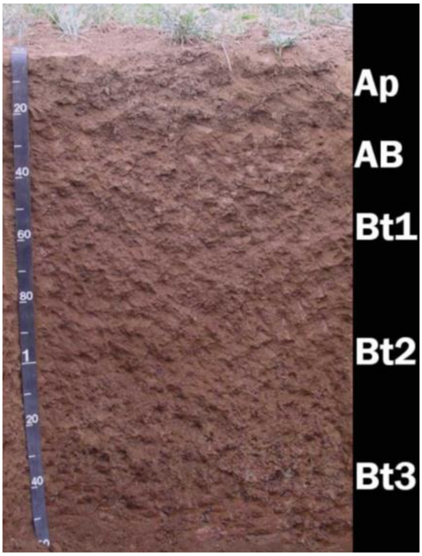


Figure 44. The Profile of Ultisols

9.1. ULTISOL SUBORDER CLASSIFICATION

Ultisols are classified into various suborders based on their specific characteristics and properties. Ultisols are divided into 5 suborders, namely Aquult, Humult, Udult, Ustult, and Xerult.

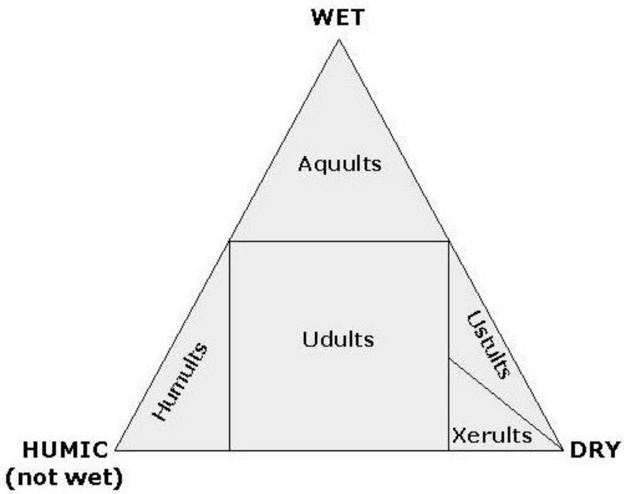


Figure 45. Suborder Diagram of Ultisols

Description:

Aquults	-	Ultisols with a water table at or near the surface for much of the year
Humults	-	Well-drained Ultisols that have high organic matter content
Udults	-	Ultisols of humid climates
Ustults	-	Ultisols of semiarid and subhumid climates
Xerults	-	Temperate Ultisols with very dry summers and moist winters

Aquult Suborder

The Aquult Suborder is a classification of Ultisols, which are a type of soil known for their low fertility and strong weathering characteristics. This suborder is characterized by its unique properties related to moisture content and geographic distribution.

Aquults are characterized by their seasonal saturation and hydric properties. They are typically found in areas with poor drainage, leading to seasonal waterlogging. This means that these soils are often saturated with water during certain parts of the year, making them unique among Ultisols.

Aquults are commonly found in regions with high annual rainfall, such as tropical and subtropical climates. They are especially prevalent in areas where heavy rains can lead to seasonal waterlogging. Examples of regions where Aquults are found include parts of Southeast Asia, Central and South America, and Africa.

The soil profile of Aquults often includes horizons with evidence of periodic saturation and leaching. These horizons can lead to the accumulation of organic matter and nutrients in specific layers. The hydric properties of Aquults play a significant role in shaping these soil profiles.

Due to their seasonal waterlogging and low natural fertility, Aquults are generally not ideal for agriculture. Instead, they are often used for forestry, wetland conservation, or as pasture for livestock. Efforts to cultivate Aquults for agriculture typically involve extensive drainage systems to mitigate waterlogging.

Aquults are ecologically important in wetland ecosystems. They provide habitat for various plant and animal species adapted to waterlogged conditions. Additionally, they play a role in water filtration and can help reduce the risk of downstream flooding by storing excess water during heavy rainfall.

Humult Suborder

The Humult Suborder is a significant classification within the Ultisol order, known for its distinctive soil characteristics and regional distribution.

Humults are typically associated with regions that have a humid climate. These soils are prevalent in areas with high annual rainfall, where they have developed under the influence of a humid, moist environment. This regional preference is due to the unique properties of Humults, which are shaped by the interaction of rainfall and soil processes.

Humult soils exhibit specific properties related to their moisture content. They often have a well-developed horizon known as an argillic horizon, which contains clay minerals. This horizon plays a crucial role in retaining moisture and nutrients, making it important for plant growth in areas with frequent rainfall.

While Humults are generally more fertile than some other Ultisol suborders, they may still require careful management for agriculture. Their natural fertility can vary depending on factors like climate, vegetation, and parent material. These soils are suitable for a variety of crops and are often used for agriculture in regions with a humid climate.

Humult soils are susceptible to erosion, especially when forest cover is removed or land is intensively cultivated. The clay-rich argillic horizon, while beneficial for moisture retention, can be easily eroded if protective measures are not taken. This makes soil conservation practices crucial in Humult-dominated regions.

Udult Suborder

The Udult Suborder is a significant classification within the Ultisol order, known for its distinctive soil characteristics and regional distribution.

Udults are closely associated with regions that experience a pronounced dry season. These soils develop under the influence of a tropical or subtropical climate characterized by a distinct wet and dry period. The Udult Suborder is often found in areas where the dry season can be quite extended, impacting soil development.

Udult soils exhibit specific properties related to their response to seasonal moisture fluctuations. They typically have a well-developed argillic horizon, which is enriched with clay minerals. This horizon plays a critical role in retaining moisture and nutrients during the dry season, allowing plants to thrive.

Udult soils are generally considered suitable for agriculture. Their natural fertility can vary depending on factors like climate, vegetation, and parent material. These soils are often used for growing crops like maize, beans, and other staple foods, making them important for food production in regions with a pronounced dry season.

While Udults are productive soils, they can be susceptible to erosion, especially during heavy rainfall at the start of the wet season. The presence of the argillic horizon, which promotes moisture retention, can also make the soil more prone to runoff and erosion when the rains first arrive. Soil conservation practices are important in Udult-dominated regions to mitigate these risks.

Ustult Suborder

The Ustult Suborder is an essential classification within the Ultisol order, characterized by specific soil properties and regional distribution.

Ustult soils are primarily found in regions with a pronounced wet-dry climate. They are prevalent in tropical and subtropical areas, often coinciding with extensive wet and dry seasons. These soils can be located in various parts of the world, including parts of Africa, South America, Southeast Asia, and the southern United States. The climate in these regions plays a crucial role in shaping the unique properties of Ustult soils.

Ustult soils exhibit several distinctive characteristics. One of the defining features is the presence of an argillic horizon, which contains a significant amount of clay minerals. This horizon contributes to the soil's ability to retain moisture and nutrients, making it suitable for agriculture. Ustults often have a reddish or yellowish coloration due to iron and aluminum oxides.

Ustult soils are typically fertile and well-suited for agriculture. The argillic horizon's clay content helps retain moisture during the dry season, making these soils valuable for crop production in areas with pronounced wet and dry periods. Farmers in Ustult-dominated regions commonly cultivate crops like maize, rice, soybeans, and cotton. The natural fertility of these soils, combined with proper land management practices, can lead to successful crop yields.

While Ustults are agriculturally productive, they can be susceptible to erosion, particularly during the onset of the wet season. The clay-rich argillic horizon can become compacted and prone to runoff if not adequately managed. Soil conservation measures, such as contour farming, terracing, and cover cropping, are essential to mitigate erosion risks and preserve the soil's productivity.

Given the importance of Ustult soils in global agriculture, sustainable land management practices are critical. Crop rotation, organic matter incorporation, and precision irrigation techniques are often employed to maintain soil health and fertility. Additionally, farmers in Ustult-dominated regions may use agroforestry systems to further enhance soil quality and promote long-term sustainability.

Xerult Suborder

The Xerult Suborder is a significant classification within the Ultisol order, notable for its specific soil properties and distribution.

Climate and Geographic Distribution: Xerult soils are primarily associated with regions that experience a semi-arid to arid climate, characterized by limited rainfall and high evaporation rates. These soils can be found in various parts of the world, including parts of North America, South America, Africa, and Australia. Xerults are adapted to the challenging conditions of these arid regions, and their properties reflect the influence of the climate.

Xerult soils exhibit distinct characteristics that make them well-suited for arid environments. They often have a relatively shallow depth, with a horizon structure that includes argillic and kandic horizons. The argillic horizon, rich in clay minerals, contributes to the soil's capacity to retain moisture, which is crucial in water-scarce areas. The kandic horizon contains accumulated clay, enhancing the soil's texture and fertility.

Despite the arid conditions of their native regions, Xerult soils can support agriculture if managed carefully. The clay content in the argillic horizon enables these soils to retain moisture, making them suitable for drought-resistant crops like sorghum, millet, and certain legumes. However, successful agriculture in Xerult-dominated regions often requires irrigation and water-efficient farming practices.

Arid regions are prone to soil erosion due to the scarcity of vegetation and the intermittent but intense rainfall events. Xerult soils are no exception. To combat erosion and preserve their productivity, soil conservation measures such as contour farming, terracing, and windbreaks are often necessary. Additionally, organic matter incorporation and mulching can improve soil structure and moisture retention.

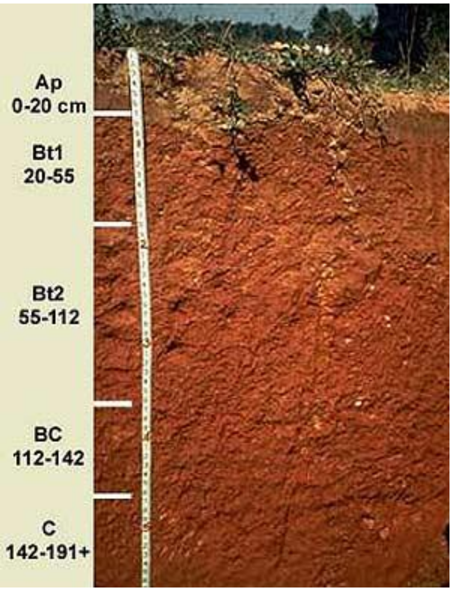
Sustainable land management practices are essential for maintaining the productivity of Xerult soils while mitigating the challenges posed by arid climates. Crop rotation, no-till farming, and the use of drought-resistant crop varieties can contribute to sustainable agriculture. Furthermore, farmers may adopt water-efficient irrigation methods, such as drip irrigation, to optimize water use. Agroforestry systems can also be beneficial in restoring and conserving soil quality in Xerult-dominated regions.

FIGURE 46
THE UDULT SOIL PROFILE AND LANDSCAPE

The Landscape of Kanhapludult

This landscape has been extensively used for agricultural production for almost 200 years. In the low-lying areas of this landscape, a reddish Bt horizon has emerged due to erosion. The average annual rainfall is about 1100 mm. The parent material for this soil is mica schist rock.

The Profile of Typic Kanhapludult

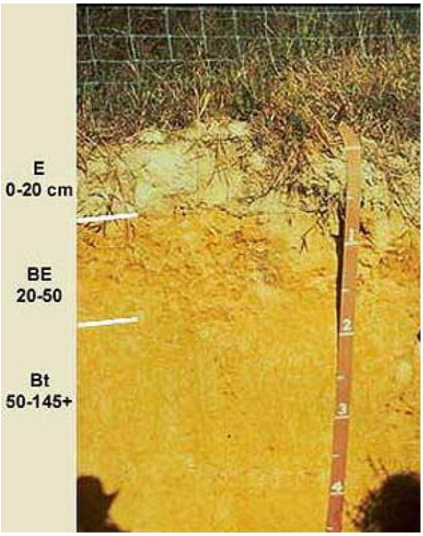


This soil is one of the types commonly found in the southern United States. It is formed from felsic igneous and metamorphic rocks. Its Bt horizon has a clayey texture with a clay content of up to 70%, dominated by low-activity clay minerals such as kaolinite and hydroxy-vermiculite.

The Landscape of Kandiudult

The coastal plain of North Carolina. Kandiudult with good drainage in the front of this photo. Poorly drained Aquult is found in the back near the row of trees. Tobacco plants can be seen growing in this area.

The Profile of Typic Kandiudult



This soil is widely distributed on the coastal plains in the southern United States, where it forms on clayey marine sediments. Although originally forested, much of it has been cleared and used for various types of agricultural crops.

Hard plinthite is used as laterite and serves as a building material in various countries where rock sources are not available. Plinthic material is extracted from the soil in the form of blocks and is then dried under the sun's heat or in an oven.

9.2. THE GLOBAL DISTRIBUTION OF ULTISOLS

Ultisols, also known as red and yellow tropical soils, are a prominent soil order found across the globe. These soils are characterized by their advanced weathering processes and relatively low natural fertility. Ultisols are predominantly located in regions with warm and humid climates, primarily in tropical and subtropical areas. They have evolved over ancient and stable landscapes that have experienced extensive weathering and leaching of essential nutrients, resulting in nutrient-poor soil conditions.

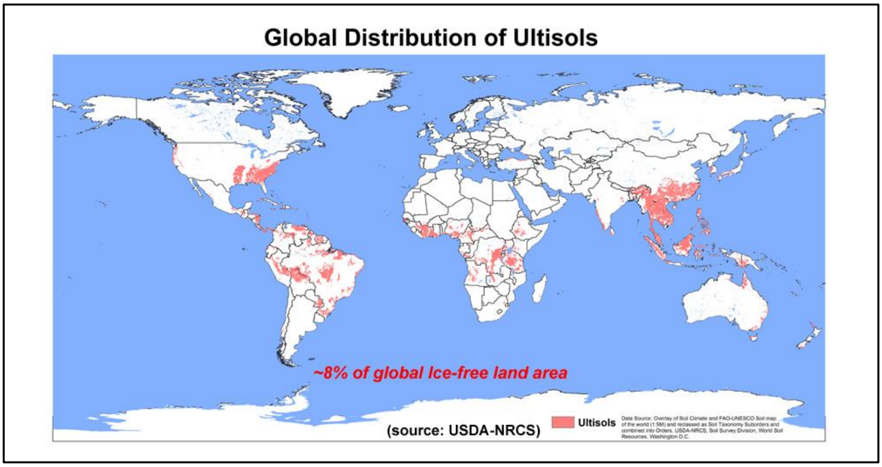


Figure 47. The Global Distribution of Ultisols

In the United States, Ultisols cover approximately 8.1% of the total land area, with a significant presence in the southern regions, accounting for about 9.2% of the country's land. These soils are extensively distributed across the southeastern states and parts of the Midwest. The warm and humid climate in these areas, coupled with the advanced weathering processes, has contributed to the formation of Ultisols.

Globally, Ultisols are widespread, encompassing approximately 8.1% of the world's land area. They are found in various parts of the world, including South America, Africa, Southeast Asia, and the Pacific Islands. These regions typically have high rainfall and warm temperatures, making Ultisols one of the dominant soil types in tropical and subtropical environments.

Due to their relatively low natural fertility, Ultisols often require soil management practices such as fertilization and liming to make them suitable for agriculture. In many tropical and subtropical regions, Ultisols are used for growing crops like cotton, soybeans, peanuts, and various types of fruit trees. Proper soil conservation and management practices are crucial to sustaining agricultural productivity while preventing soil degradation in Ultisol-rich areas.

CHAPTER X
OXISOLS

Oxisols are a distinct and important soil order known for their highly weathered, iron and aluminum-rich, and acidic characteristics. They are primarily found in tropical and subtropical regions of the world, where the climate is warm and humid throughout the year. Oxisols are known for their bright red or yellow coloration, which is a result of the accumulation of iron and aluminum oxides in the soil.

Oxisols are soils that have developed in highly weathered tropical regions around the world. These soils consist of highly weathered minerals and often contain significant amounts of iron and aluminum oxides. Oxisols cover approximately 7.5% of the world's land area. In the United States, they make up about 0.02% of the total land area, primarily in Hawaii.

Oxisols cover approximately 8% of the world's land area, and in Indonesia, these soils are predominantly found in Sumatra, Sulawesi, Kalimantan, and Papua. Oxisols are known by different names in other soil classification systems, such as Lateritic and Ferralsol.

One of the defining features of Oxisols is their advanced level of weathering, which has led to the depletion of essential nutrients like calcium, magnesium, and potassium. This low natural fertility makes Oxisols generally unsuitable for agriculture without extensive soil management practices, such as liming and fertilization.

These soils are particularly widespread in regions like the Amazon Basin in South America, parts of Africa, Southeast Asia, and Australia. They often develop on old, stable landforms that have undergone millions of years of weathering, resulting in nutrient-poor but highly weathered soils. Despite their limitations for agriculture, Oxisols play a vital role in natural ecosystems. They are often found in tropical rainforests and other natural habitats, where they support a diverse range of plant and animal species. Additionally, Oxisols are valuable for their ability to sequester carbon, helping to mitigate the effects of climate change by storing organic matter in their deep horizons.

Most Oxisols are characterized by very low natural fertility due to limited nutrient storage, high phosphorus retention by oxide minerals, and low cation exchange capacity (CEC). Most of the nutrients in Oxisol environments are concentrated in plant growth zones and locations where the decomposition of plant residues is actively occurring. Despite their low inherent fertility, Oxisols can become productive with the addition of lime and fertilizers.

Oxisols are a type of soil that are highly weathered and characterized by their low natural fertility. They are typically found in tropical and subtropical regions with high temperatures and rainfall. The global distribution of Oxisols is influenced by factors such as climate, parent material, and topography. According to (Padmanabhan *et al*., 2011), the presence of a kandic horizon is a characteristic feature of Oxisols, and their geographic extent would increase in the intertropical belt with an iso-soil temperature regime. This suggests that Oxisols are more prevalent in regions with specific climatic conditions.

In terms of soil classification, Oxisols are classified as one of the soil orders in the World Reference Base for Soil Resources (WRB). Madari et al. McDowell *et al*. (2012) conducted a study where they produced separate models for different soil orders, including Oxisols. This indicates that Oxisols have distinct characteristics that differentiate them from other soil orders. Additionally, the study by George *et al*. (2006) focused on the dynamics of organic phosphorus in the rhizosphere of plants grown in Oxisols. They found that plants with enhanced rhizosphere phosphatase activity were able to deplete more organic phosphorus from P-deficient Oxisols.

Overall, the global distribution of Oxisols is influenced by climate, parent material, and soil classification. They are predominantly found in tropical and subtropical regions with specific climatic conditions. Oxisols have distinct characteristics, such as the presence of a kandic horizon, that differentiate them from other soil orders. Understanding the distribution and characteristics of Oxisols is important for agricultural production and land management in these regions.

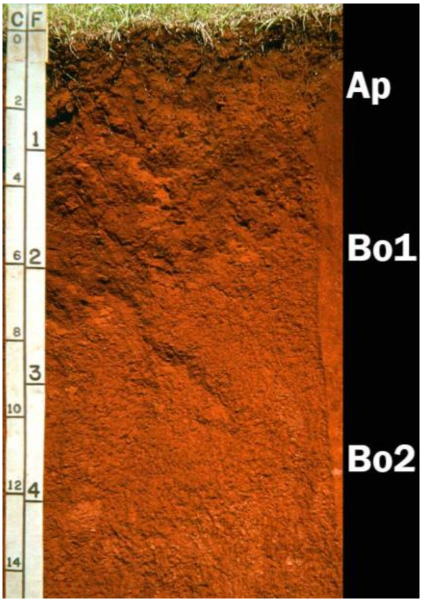


Figure 48. The Profile of Oxisols

10.1. OXISOL SUBORDER CLASSIFICATION

Oxisols are classified into suborders based on various soil properties and characteristics. Oxisols are divided into 5 suborders, namely Aquox, Torrox, Ustox, Perox, and Udox.

Description:

Aquoxs	-	Oxisols with a water table at or near the surface for much of the year
Torroxs	-	Oxisols of arid climates
Ustoxs	-	Oxisols of semiarid and subhumid climates
Peroxs	-	Oxisols of continuously humid climates, where precipitation exceeds evapotranspiration in all months
Udoxs	-	Oxisols of humid climates

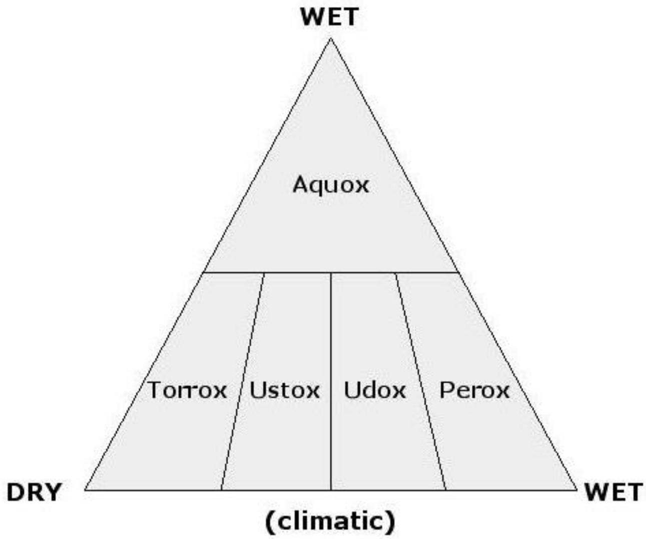


Figure 49. Suborder Diagram of Oxisols

Aquox Suborder

Aquox is a suborder of Oxisols, which are soils known for their high degree of weathering and development in tropical regions around the world. These soils are characterized by a significant accumulation of iron and aluminum oxides and are typically found in areas with a long history of weathering and leaching.

The Aquox suborder is associated with Oxisols that have a high water table, especially during certain times of the year. This suborder is often found in regions with a distinct wet and dry season, where the water table fluctuates significantly. The presence of a high water table can influence the chemical processes that occur within the soil, including the leaching of minerals and nutrients.

One key characteristic of Aquox suborder soils is their ability to retain moisture, even during dry periods. This is due to the high clay content in these soils, which helps them hold water for extended periods. However, the same clay content can also result in poor drainage and potential issues with soil saturation, which can impact plant growth.

The Aquox suborder is important for agriculture in some regions, as the soils can be fertile and support various crops. However, the high clay content and water table fluctuations can pose challenges for farming practices, requiring careful water management and soil preparation.

Torrox Suborder

The Torrox suborder is a classification within the Oxisols soil order, which is known for its highly weathered and leached nature, primarily found in tropical regions across the world. Oxisols are characterized by their low natural fertility due to the depletion of essential nutrients as a result of extensive weathering processes.

The Torrox suborder, in particular, is associated with Oxisols that exhibit a high level of leaching and weathering. These soils are typically found in regions with a prolonged dry season, and they often have a reddish coloration due to the presence of iron and aluminum oxides. The name "Torrox" is derived from the Spanish word "torre," meaning "tower," which references the towering profile of the horizon in these soils.

One of the defining features of Torrox suborder soils is their low nutrient content. The intense weathering and leaching processes lead to the removal of essential nutrients, leaving the soil with very little fertility. As a result, agriculture in Torrox soils can be challenging without substantial nutrient inputs and soil management practices.

Torrox soils are also known for their coarse texture, which contributes to their low water-holding capacity. This can be problematic in regions with irregular rainfall patterns, as the soils may struggle to retain moisture during dry periods. Adequate irrigation and water management become crucial for agriculture in Torrox soils.

Ustox Suborder

The Ustox suborder is a classification within the Oxisols soil order, known for its highly weathered and leached nature, primarily found in tropical regions across the world. Oxisols are characterized by their low natural fertility due to extensive weathering processes, which result in the depletion of essential nutrients.

Ustox soils, in particular, exhibit a unique set of characteristics. They are found in regions with distinct wet and dry seasons. During the wet season, these soils often become waterlogged due to poor drainage, which can create challenges for agriculture. In contrast, during the dry season, they may experience drought stress due to their coarse texture and low water-holding capacity.

One of the defining features of Ustox suborder soils is their intense weathering, which leads to the formation of iron and aluminum oxides. These oxides give the soils a reddish or yellowish coloration, which is a common visual cue for identifying Ustox soils. The high iron content can also lead to challenges in nutrient availability for plants, as iron can be toxic to some crops at elevated levels.

Ustox soils are generally low in natural fertility. The extensive leaching processes they undergo strip away essential nutrients, leaving the soils with very little nutrient content. Therefore, successful agriculture in Ustox soils often requires significant nutrient inputs and careful soil management practices to maintain soil fertility.

Perox Suborder

The Perox suborder is a classification within the Oxisols soil order, which is known for its extensive weathering and leaching processes. Oxisols, including those in the Perox suborder, are typically found in tropical regions and are characterized by their low natural fertility due to the depletion of essential nutrients.

One of the distinctive features of the Perox suborder is its strong weathering and leaching of minerals, leading to the accumulation of iron and aluminum oxides in the soil. These oxides give the soil a reddish or yellowish coloration, making it easily identifiable. However, the presence of these oxides can also affect nutrient availability, as they can bind nutrients and make them less accessible to plants.

Perox suborder soils are often found in regions with a pronounced dry season, which can lead to challenges related to drought stress for plants. These soils have a coarse texture and low water-holding capacity, making it difficult for plants to access water during extended dry periods.

Due to their low natural fertility, successful agriculture in Perox suborder soils typically requires significant nutrient inputs and careful soil management practices. Farmers may need to apply fertilizers and other soil amendments to enhance soil fertility and make it suitable for crop cultivation.

Udox Suborder

The Udox suborder is a classification within the Oxisols soil order, which is known for its extensive weathering and leaching processes. Oxisols, including those in the Udox suborder, are typically found in tropical regions and are characterized by their low natural fertility due to the depletion of essential nutrients.

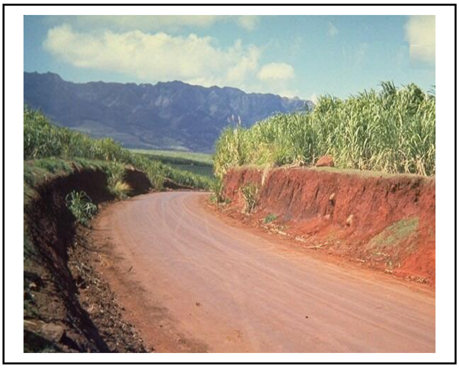
One of the distinctive features of the Udox suborder is its strong weathering and leaching of minerals, leading to the accumulation of iron and aluminum oxides in the soil. These oxides give the soil a reddish or yellowish coloration, making it easily identifiable. However, the presence of these oxides can also affect nutrient availability, as they can bind nutrients and make them less accessible to plants.

Udox suborder soils are often found in regions with a pronounced dry season, which can lead to challenges related to drought stress for plants. These soils have a coarse texture and low water-holding capacity, making it difficult for plants to access water during extended dry periods.

Due to their low natural fertility, successful agriculture in Udox suborder soils typically requires significant nutrient inputs and careful soil management practices. Farmers may need to apply fertilizers and other soil amendments to enhance soil fertility and make it suitable for crop cultivation.

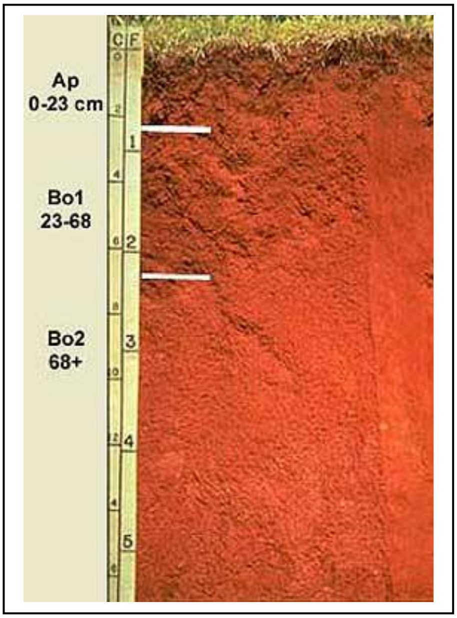
FIGURE 50
THE USTOX SOIL PROFILE AND LANDSCAPE

The Landscape of Eutrustox



The soils in this highland landscape have formed from underlying igneous rocks. These soils are widely used for the production of pineapples, grazing, sugarcane, and as a natural reserve habitat.

The Profile of Rhodic Eutrustox



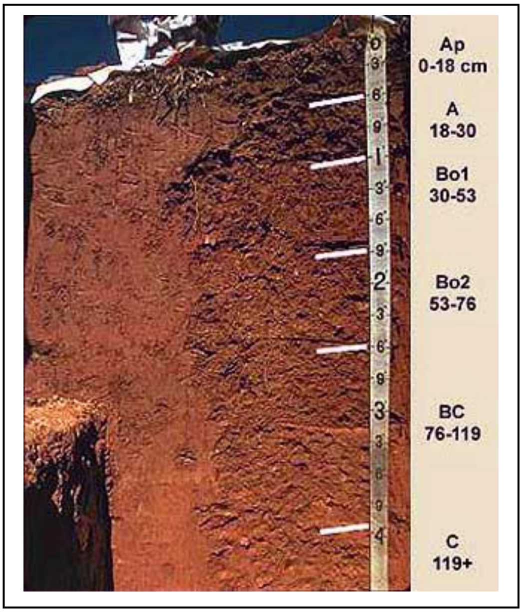
This soil is very deep, well-drained, and originates from the weathering of igneous parent rocks. It is found in highland areas with slopes ranging from 0 to 25%. The average annual rainfall is approximately 600 mm, and the average annual temperature is around 32°C. This soil is located in the Molokai Series and is used for pineapple production, grazing, sugarcane cultivation, and as a natural reserve habitat. The oxic horizon (Bo horizon) in this Molokai soil is slightly acidic to neutral, with a pH value of around 6.5.

FIGURE 51
THE UDOX SOIL PROFILE AND LANDSCAPE

The Landscape of Hapludox

Hapludox is found on the terraced slopes in the middle and back of this photo. This soil is formed from tuff sediment. This Oxisol soil is used for cultivating crops such as sugarcane, plantations, and pineapples. Some areas are utilized for grazing as well.

The Profile of Inceptic Hapludox



This soil is formed from advanced weathering of tuff breccia. It has low fertility status and a high capacity for phosphorus fixation. The soil has good drainage and is suitable for agriculture with adequate agricultural inputs available.

10.2. THE GLOBAL DISTRIBUTION OF OXISOLS

The global distribution of Oxisols is primarily in tropical regions, such as parts of South America, Africa, Southeast Asia, and Australia. In these areas, warm temperatures and high rainfall contribute to the intense weathering processes that lead to the formation of Oxisols. For example, the Amazon Basin in South America contains vast expanses of Oxisols, which are home to lush rainforests. Similarly, parts of Africa's Congo Basin and Southeast Asia's tropical rainforests are situated on Oxisols.

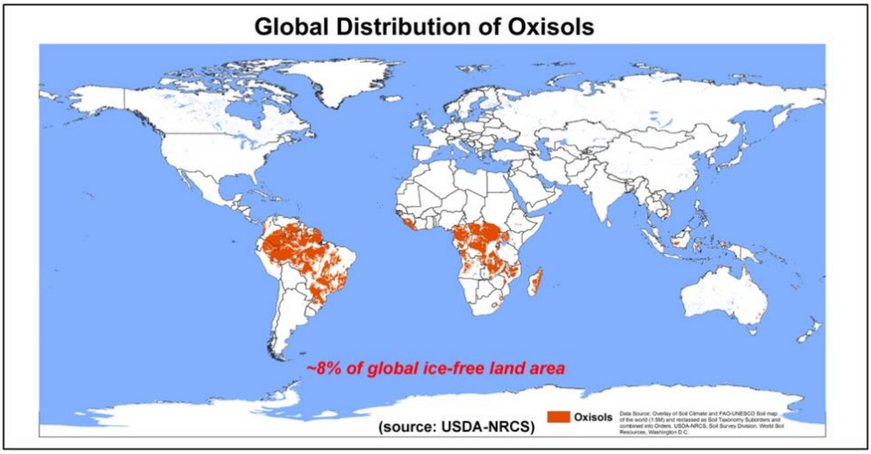


Figure 52. The Global Distribution of Oxisols

Despite their natural fertility limitations, Oxisols are essential for agriculture in many tropical regions. Farmers in these areas often rely on soil management practices like slash-and-burn agriculture, crop rotation, and the addition of organic matter to improve soil fertility and productivity. Oxisols are also important for natural ecosystems, as they support diverse flora and fauna in tropical rainforests.

Oxisols are a significant soil order found predominantly in tropical regions, covering approximately 7.5% of the Earth's land area. They are characterized by their low natural fertility, high iron and aluminum oxide content, and limited nutrient availability.

CHAPTER XI
ARIDISOLS

Aridisols, as the name suggests, are a soil order primarily found in arid and semi-arid regions of the world. These soils have distinct characteristics that make them well-suited to such dry environments. Aridisols cover approximately 12% of the Earth's ice-free land area, making them one of the major soil orders globally. Aridisols are soils that contain CaCO3 in dry regions, showing the development of several sub-surface horizons. They are characterized by their consistently dry conditions throughout the year and limited leaching. Aridisols have sub-surface horizons where accumulations of clay, calcium carbonate, silica, salts, and gypsum are found. Materials like soluble salts, gypsum, and $CaCO_3$ tend to be leached in more humid climates. The equivalent soil classification for Aridisols in other systems is Xerosols.

A key characteristic of Aridisols is their aridic moisture regime, meaning they experience limited soil moisture throughout the year due to low precipitation levels and high evaporation rates. This regime has a significant impact on their properties and fertility. Aridisols often have horizon development patterns that reflect their moisture limitations, with accumulations of soluble salts, clay, and calcium carbonate in certain horizons.

Aridisols pose several challenges for agriculture due to their limited moisture and fertility. However, with proper management practices like irrigation, soil amendment with organic matter, and the selection of drought-resistant crops, these soils can be made productive. Additionally, Aridisols play a vital role in supporting native vegetation and ecosystems in arid regions, providing habitat for drought-adapted plant and animal species.

Aridisols are a significant soil order found in arid and semi-arid regions, covering approximately 12% of the Earth's ice-free land area. They are characterized by their aridic moisture regime, which poses challenges for agriculture but also supports unique ecosystems adapted to arid conditions. Proper soil management practices are essential to make Aridisols productive for agriculture in these dry environments.

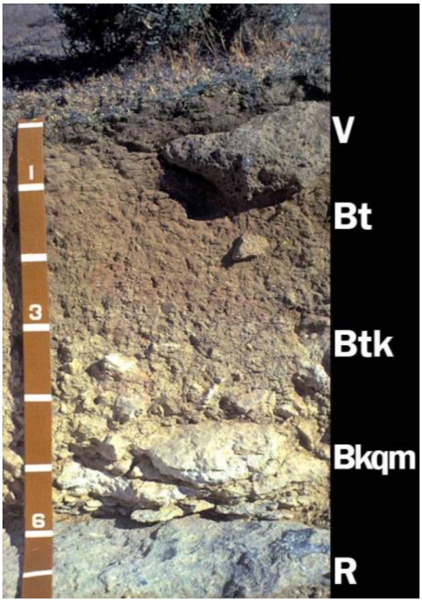


Figure 53. The Profile of Aridisols

Aridisols are a type of soil order that is characterized by extreme aridity and minimal rainfall regimes (Pace et al., 2009). They are typically found in regions with limited water availability and are often associated with desert and semi-arid environments (Pace et al., 2009). Aridisols are formed through the accumulation of minerals such as calcite and gypsum, which are indicative of arid conditions (Pace et al., 2009). These soils are often found in channellag and overbank deposits, suggesting that they have been scavenged during landscape degradation (Batezelli et al., 2018).

Aridisols have been identified in various regions, including the Karoo Basin in South Africa (Pace et al., 2009). However, their occurrence is restricted and they have not been verified in other areas of the basin (Batezelli et al., 2018). The distribution of micronutrients in Aridisols is lower compared to other soil orders such as Inceptisols and Entisols (Dhaliwal et al., 2021). Understanding the properties and distribution of Aridisols is important for agricultural and environmental management in arid regions.

11.1. ARIDISOL SUBORDER CLASSIFICATION

Aridisols are classified into several suborders based on specific soil properties and characteristics. Aridisols are divided into 7 suborders, namely: Cryid, Salid, Durid, Gypsid, Argid, Calcid, and Cambid.

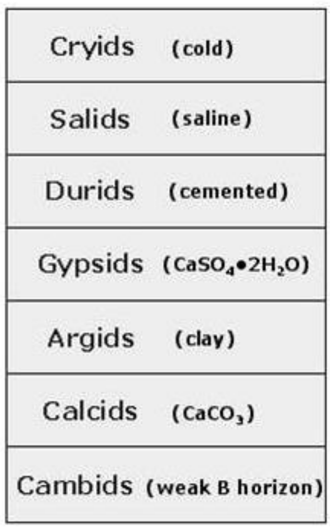


Figure 54. Suborder Diagram of Aridisols

Description:

Cryids - Aridisols of cold climates
Salids - Aridisols with soluble salt accumulation
Durids - Aridisols wit SiO_2 cemented subsurface horizon
Gypsids - Aridisols with gypsum accumulation
Argids - Aridisols with clay accumulation
Calcids - Aridisols with $CaCO_3$ accumulation
Cambids - Aridisols with a weakly developed B Horizon

Cryid Suborder

The Cryid Suborder is a classification within the Aridisols order of soils, which are typically found in arid and semi-arid regions with limited rainfall. The term "Cryid" signifies a unique characteristic of these soils related to their moisture regime.

Cryid is one of the seven suborders of Aridisols recognized by the United States Department of Agriculture (USDA) soil taxonomy. The term "Cryid" is derived from "cry," which refers to the presence of cryoturbation or freeze-thaw processes in these soils. Cryoturbation is the mixing of soil materials caused by the expansion and contraction of water as it freezes and thaws, leading to unique soil properties.

Cryid soils are typically found in arid regions with cold winters, where freeze-thaw cycles play a significant role in shaping soil characteristics. These soils are commonly encountered in regions like the western United States, Central Asia, and parts of South America, where arid conditions are coupled with seasonal freezing temperatures.

Cryid soils often display a series of subsurface horizons that result from the freeze-thaw processes. These horizons can include cryoturbated horizons (designated as "Cryic" horizons) where material has been mixed by frost action. Additionally, the presence of soluble salts, gypsum, and other minerals may contribute to unique textural and chemical properties in these soils.

Cryid soils present challenges for agriculture due to their limited moisture availability and potential for soil degradation through cryoturbation. The cyclic expansion and contraction of soil particles can cause soil structure disruption, making it difficult for plant roots to establish themselves. Consequently, these soils are often not suitable for intensive agricultural activities but may be used for grazing, dryland farming, or as natural rangeland.

Managing Cryid soils requires careful consideration of the freeze-thaw dynamics and moisture availability. Conservation practices may involve minimizing soil disturbance, using cover crops to protect against erosion, and selecting drought-resistant crop varieties. Proper irrigation management and soil amendments may also be employed to enhance agricultural productivity in regions with Cryid soils.

The Cryid Suborder of Aridisols is characterized by its unique response to freeze-thaw processes, which result in distinctive subsurface horizons and physical properties. These soils are primarily found in arid regions with cold winters and present challenges for agriculture due to limited moisture availability and potential soil disruption. Effective soil conservation and management practices are essential for sustainable land use in areas dominated by Cryid soils.

Salid Suborder

The Salid Suborder is a classification within the Aridisols order of soils, which are typically found in arid and semi-arid regions characterized by limited precipitation. The "Salid" designation relates to a significant feature of these soils associated with soluble salts.

Salid is one of the suborders within the Aridisols order, defined by the presence of soluble salts that accumulate within the soil. These salts are typically found in the subsurface horizons, giving the soil its characteristic name. Salid soils are commonly associated with arid and semi-arid regions, where evaporation rates exceed precipitation, leading to salt accumulation.

Salid soils are prevalent in arid and semi-arid regions across the globe, including areas in North America, South America, Asia, Africa, and Australia. The specific salts that accumulate can vary depending on the region, but common examples include sodium chloride (table salt) and calcium sulfate (gypsum). Regions with high evaporation rates and limited leaching are more likely to develop Salid soils.

Salid soils often exhibit distinct subsurface horizons with salt accumulations. These salts can be harmful to plants because they interfere with water and nutrient uptake. In extreme cases, the salts can create saline or sodic conditions, further hindering plant growth. The surface of Salid soils may also have a crust or efflorescence of salts, making them visibly different from non-saline soils.

Salid soils present significant challenges for agriculture because of the detrimental effects of salt on plant growth. Salt-affected soils can lead to reduced crop yields and, in severe cases, render land unsuitable for agriculture. Management strategies for Salid soils often involve leaching to remove excess salts, improving drainage, and selecting salt-tolerant crops. However, successful agricultural use of Salid soils can be challenging and may require ongoing soil and water management practices.

Conservation of Salid soils involves preventing further salt accumulation and reclaiming salt-affected land. Techniques like proper irrigation management, leaching to remove salts, and the use of gypsum to displace sodium ions can help rehabilitate salt-affected soils. Additionally, soil amendments, crop rotation, and re-vegetation with salt-tolerant species may be employed to restore the productivity of Salid soils while minimizing environmental impacts.

The Salid Suborder of Aridisols is characterized by the accumulation of soluble salts in the soil, typically found in arid and semi-arid regions. These salts can pose significant challenges for agriculture and land use due to their adverse effects on plant growth. Effective soil management, including salt leaching and the use of salt-tolerant crops, is essential for sustainable land use in areas dominated by Salid soils.

Durid Suborder

The Durid Suborder is a classification within the Aridisols order of soils, which are primarily found in arid and semi-arid regions characterized by limited precipitation. The term "Durid" is associated with a specific feature of these soils related to the duripan horizon, a hardened and cemented layer that can restrict root growth and water movement.

The Durid Suborder is defined by the presence of a duripan horizon within the soil profile. A duripan is a dense, cemented layer that forms below the surface due to the accumulation of minerals and organic matter. This duripan layer is often cemented by calcium carbonate (lime) and may restrict root penetration and water infiltration. Duripans can be a significant limitation for plant growth and agriculture in arid regions.

Durid soils are commonly found in arid and semi-arid regions around the world, including parts of North America, South America, Africa, Asia, and Australia. The formation of duripans is closely related to the arid climate, where the rate of evaporation often exceeds precipitation, leading to the accumulation of minerals like calcium carbonate in the subsoil.

The most distinctive feature of Durid soils is the presence of the duripan horizon. This layer can vary in thickness and depth but typically occurs within the lower part of the soil profile. It is dense, hard, and often has a cemented texture. The duripan layer restricts water movement, making drainage and root penetration difficult. This can pose significant challenges for agriculture and land use in affected areas.

The duripan horizon in Durid soils can limit agricultural productivity due to its restrictive nature. It prevents deep root penetration, making it challenging for crops to access water and nutrients stored in deeper soil layers. As a result, agricultural practices in Durid soil regions often require careful consideration of irrigation, soil amendment, and crop selection. Some strategies involve breaking up the duripan layer mechanically or through chemical treatments to improve soil structure.

Conservation and rehabilitation efforts for Durid soils often focus on improving soil structure and fertility. Strategies may include deep tillage to break up the duripan, the addition of organic matter to increase soil carbon content, and the use of cover crops to enhance soil health. Sustainable land management practices can help mitigate the limitations posed by the duripan horizon and make these soils more suitable for agriculture and other land uses.

The Durid Suborder of Aridisols is characterized by the presence of a duripan horizon, a dense and cemented layer in the soil profile. These soils are typically found in arid and semi-arid regions worldwide and pose challenges for agriculture due to limited root penetration and restricted water movement. Effective soil management practices are essential for sustainable land use in Durid soil regions, including strategies to break up the duripan layer and improve soil fertility.

Gypsid Suborder

The Gypsid Suborder is a classification within the Aridisols order of soils, which are primarily found in arid and semi-arid regions characterized by limited precipitation. The term "Gypsid" is associated with a specific feature of these soils related to the presence of gypsum (calcium sulfate) accumulations.

The Gypsid Suborder is defined by the significant accumulation of gypsum within the soil profile. Gypsum is a mineral that contains calcium and sulfur and can be found in various forms within these soils. This accumulation of gypsum affects soil properties and fertility, making it a distinctive characteristic of Gypsid soils.

Gypsid soils are commonly found in arid and semi-arid regions around the world, including parts of North America, South America, Africa, Asia, and Australia. These regions typically have a dry climate, where the rate of evaporation exceeds precipitation. This climatic condition leads to the accumulation of gypsum in the soil over time.

Gypsid soils often exhibit unique physical characteristics due to the presence of gypsum. Gypsum accumulations can take various forms, such as nodules, crusts, or layers. These gypsum-rich horizons can restrict root penetration and impact soil structure. Gypsum's presence can also improve soil stability and reduce erosion, which is beneficial in arid regions prone to wind and water erosion.

The presence of gypsum in Gypsid soils can both benefit and challenge land use. On one hand, the improved soil structure resulting from gypsum can enhance water infiltration and reduce erosion, making it suitable for certain crops. On the other hand, excessive gypsum accumulation can limit root growth and affect nutrient availability, posing challenges for agriculture. Effective soil management practices, such as gypsum amendment and proper irrigation, are important for optimizing crop production in Gypsid soil areas.

Conservation and rehabilitation efforts for Gypsid soils aim to improve soil fertility and reduce the negative impacts of gypsum accumulation. Strategies may include the addition of organic matter to increase soil carbon content, proper irrigation management to leach excess salts and gypsum, and crop selection that is tolerant to gypsum-rich soils. Sustainable land management practices can help make Gypsid soils more suitable for agriculture and other land uses.

The Gypsid Suborder of Aridisols is characterized by the significant accumulation of gypsum within the soil profile, which can affect soil properties and fertility. These soils are commonly found in arid and semi-arid regions and present both challenges and opportunities for land use. Effective soil management practices are essential for optimizing crop production and sustainable land use in Gypsid soil regions.

Argid Suborder

The Argid Suborder is a significant classification within the Aridisols soil order, specifically tailored to soils found in arid and semi-arid regions characterized by limited rainfall and pronounced dry conditions. This suborder is associated with specific soil properties and features that make it distinct within the realm of Aridisols.

The Argid Suborder is defined by the presence of argillic horizons in the soil profile. Argillic horizons are layers rich in clay minerals, which can significantly impact the soil's physical, chemical, and hydraulic properties. These horizons often develop as a result of weathering processes in arid environments.

Argid soils are typically found in arid and semi-arid regions across the globe. These regions are characterized by low annual precipitation and often feature challenging environmental conditions for plant growth. As a result, soils within the Argid Suborder have evolved specific characteristics to adapt to these arid conditions. They are found in areas of North America, South America, Africa, Asia, and Australia, among others.

The clay-rich argillic horizons of Argid soils play a crucial role in the soil's physical properties. The high clay content gives these soils the ability to retain water and nutrients, which can be advantageous for plant growth in arid regions. However, this clay-rich composition can also lead to slow water infiltration and drainage, potentially causing issues like waterlogging under certain conditions.

Argid soils can pose both challenges and opportunities for agriculture. While they have the capacity to retain water and nutrients, their dense clay texture can be prone to compaction, which restricts root growth and water infiltration. Farmers and agriculturalists in regions with Argid soils must employ proper soil management practices, such as the addition of organic matter, to improve soil structure and fertility.

Sustainable land management practices are crucial in areas dominated by Argid soils. Implementing techniques like crop rotation, reduced tillage, and efficient irrigation management can help maximize crop productivity while minimizing soil erosion and degradation. Soil conservation practices, such as contour farming and the use of cover crops, are also valuable tools for maintaining soil health in Argid Suborder regions.

the Argid Suborder of Aridisols encompasses soils that have adapted to arid and semi-arid environments by developing argillic horizons rich in clay minerals. These soils have a distinct set of properties that can be both beneficial and challenging for agriculture. Sustainable land management practices are vital to optimize land use and prevent soil degradation in regions characterized by Argid soils.

Calcid Suborder

The Calcid Suborder is an important classification within the Aridisols soil order, specifically designed for soils found in arid and semi-arid regions where calcium carbonate ($CaCO_3$) plays a significant role in soil development.

The defining feature of the Calcid Suborder is the significant accumulation of calcium carbonate in the soil profile. This accumulation typically occurs in the form of calcium carbonate nodules or coatings on soil particles. It is a result of various processes, including the upward movement of water through the soil, which carries dissolved calcium ions that precipitate when they encounter the arid or semi-arid conditions and become less soluble.

Calcid soils are primarily found in arid and semi-arid regions around the world. These regions are characterized by low rainfall and high evaporation rates, which contribute to the accumulation of calcium carbonate. Calcid soils can be found in various continents, including North America, South America, Africa, Asia, and Australia, where they often dominate the landscape in arid ecosystems.

The accumulation of calcium carbonate in Calcid soils can significantly influence their properties. One of the most notable effects is an increase in soil pH, making these soils alkaline. This alkaline pH can affect nutrient availability to plants and may require soil amendments to improve plant growth. Additionally, the presence of calcium carbonate nodules can make these soils hard and compacted, which can affect root penetration and water infiltration.

Calcid soils present unique challenges for agriculture due to their alkaline pH, high calcium carbonate content, and often limited water-holding capacity. These factors can limit the types of crops that can be successfully grown without appropriate soil management practices. Amendments like organic matter and sulfur may be needed to modify soil pH and improve fertility. Additionally, careful irrigation management is essential to prevent the buildup of salts in the root zone.

Sustainable land management practices are crucial in regions dominated by Calcid soils. Conservation measures like no-till farming, crop rotation, and the use of cover crops can help improve soil structure, reduce erosion, and enhance nutrient cycling. Proper irrigation techniques that minimize the risk of salt accumulation in the root zone are also essential for maintaining soil health and agricultural productivity in Calcid Suborder regions.

The Calcid Suborder of Aridisols represents soils that have undergone significant calcium carbonate accumulation in arid and semi-arid environments. These soils pose unique challenges for agriculture due to their alkaline pH and calcium carbonate content, but with appropriate management practices, they can support sustainable land use and mitigate issues associated with soil degradation.

Cambid Suborder

The Cambid Suborder is a significant classification within the Aridisols soil order, tailored for soils found in arid and semi-arid regions. The Cambid Suborder is characterized by its cambic horizon, which is a diagnostic subsurface horizon that exhibits evidence of horizon alteration and leaching. This horizon often displays a change in color, structure, and mineral content compared to the underlying material. It represents a transitional zone between the more weathered horizons above and the less weathered parent material below. Cambic horizons are typically well-drained and may contain increased levels of clay, organic matter, or various minerals.

Cambic horizons form as a result of leaching and alteration processes in arid and semi-arid soils. These soils often experience limited rainfall, which causes minerals to migrate downward through the soil profile. Over time, this leaching process can lead to the development of cambic horizons. The altered characteristics in the cambic horizon can influence the soil's physical and chemical properties, affecting its suitability for various land uses.

Cambid Suborder soils can be found in arid and semi-arid regions worldwide. These regions are characterized by low and erratic precipitation, which contributes to the development of cambic horizons in the soil profiles. They are prevalent in continents such as North America, South America, Africa, Asia, and Australia, where arid ecosystems and landscapes are common.

Cambic soils present both challenges and opportunities for agriculture. On the one hand, the cambic horizon can enhance drainage and aeration, making these soils suitable for certain crops. However, the altered properties in the cambic horizon may also affect nutrient retention and availability. Proper soil management practices, such as fertilization and irrigation, are essential to optimize crop production in Cambid Suborder soils. Additionally, sustainable farming techniques, such as crop rotation and conservation tillage, can help maintain soil health.

Sustainable land management practices are crucial for preserving and utilizing Cambid Suborder soils. These practices include soil conservation measures, such as erosion control, contour farming, and maintaining vegetative cover. By preventing erosion and managing soil nutrient levels, Cambid soils can continue to support agriculture and other land uses while minimizing the risk of degradation.

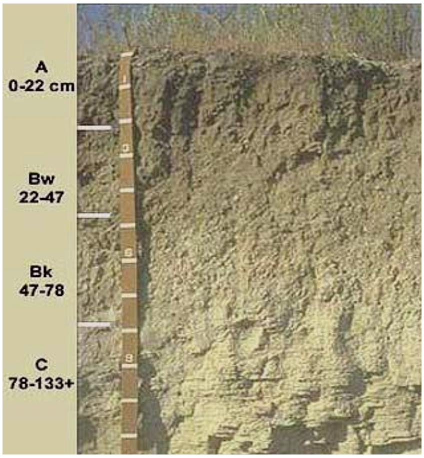
The Cambid Suborder within the Aridisols soil order represents soils with cambic horizons that indicate alteration and leaching processes in arid and semi-arid regions. These soils are distributed globally and play a critical role in agriculture and land management. Proper soil conservation and sustainable farming practices are essential for maintaining the health and productivity of Cambid soils in these challenging environments.

FIGURE 55
THE CALCID SOIL PROFILE AND LANDSCAPE

The Landscape of Haplocalcid

These soils are formed on dusty lacustrine sediments, with the accumulation of calcium carbonate in the subsoil layer. The average annual rainfall is around 300 mm; however, agricultural production may be feasible with the availability of irrigation water. The laminar sediments that make up these soils are clearly visible at the bottom of the soil profile and can slowly be penetrated by water, causing drainage problems.

The Profile of Xeric Haplocalcid



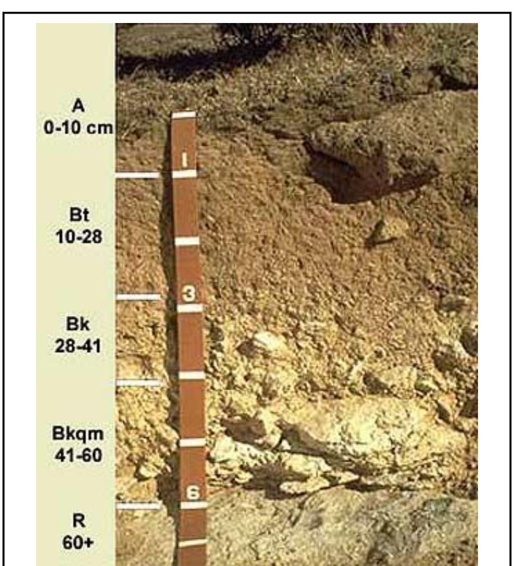
The plate-like structure in the C horizon indicates lacustrine sediments, which are the parent material of this soil. Soil development occurs slowly in this arid climate, and the calcium carbonate derived from this parent material is leached slowly from the soil profile. Meanwhile, in the subsoil, there is an accumulation of calcium carbonate, making the entire profile somewhat alkaline. Optimal leaching occurs in the Bw horizon, leading to the development of a blocky structure and a bright soil color. At the same time, carbonates will move to the lower profile, and clay translocation in the upper profile will begin.

FIGURE 56
THE DURID SOIL PROFILE AND LANDSCAPE

The Landscape of Argidurid

Soil in this landscape typically features a duripan with silica and $CaCO^3$ as binders at a relatively shallow depth. The duripan impedes root growth downward and the movement of water within the profile. This landscape experiences an average annual rainfall of about 300 mm and is mostly utilized for grazing livestock.

The Profile of Xeric Argidurid



This soil is found in basalt plains and terraces. It is relatively deep compared to the parent rock and has a duripan with lime and silica binders at a shallow depth. In this photo, the basalt parent rock is visible at the bottom of the profile. The presence of a duripan and shallow basalt rock like this can be problematic for technical activities that require excavation.

11.2. THE GLOBAL DISTRIBUTION OF ARIDISOLS

Aridisols are a significant soil order with a global distribution, primarily found in arid and semi-arid regions around the world. These soils are characterized by their dry conditions, which persist for a significant part of the year. Aridisols make up about 12% of the world's ice-free land area. They are typically associated with desert landscapes and are essential components of these ecosystems.

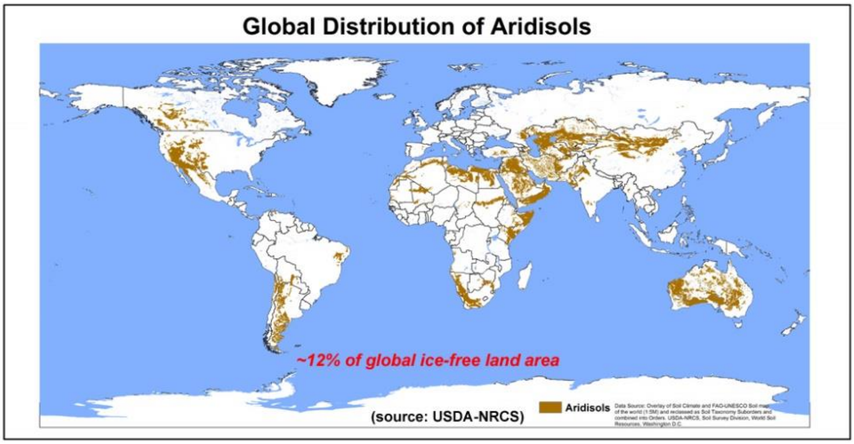


Figure 57. The Global Distribution of Aridisols

Aridisols are found on nearly every continent, with particularly extensive occurrences in regions like the southwestern United States, northern Mexico, parts of South America, northern Africa, the Middle East, and central Asia. These soils are often found in regions where water is a limiting factor for agriculture and other land uses. Their distribution is closely tied to arid and semi-arid climatic conditions characterized by low precipitation and high evaporation rates.

The properties of Aridisols vary depending on their specific location, parent material, and local climate. They typically have a horizons structure that reflects the influence of arid processes, including the accumulation of soluble salts and minerals in lower horizons. These soils are often characterized by their low organic matter content and limited biological activity due to the harsh arid environment.

Despite their limitations, Aridisols have been used for various agricultural activities, often with the help of irrigation. They can support crops like wheat, cotton, and various types of fruit trees when water resources are adequately managed. However, the fragile nature of these ecosystems makes sustainable land management crucial to prevent soil degradation and desertification, which are ongoing challenges in many arid regions.

Aridisols are a globally distributed soil order found in arid and semi-arid regions across the world. They play a crucial role in supporting vegetation and agriculture in these challenging environments. However, their sustainable management is essential to prevent land degradation and desertification, which can have far-reaching ecological and economic consequences.

CHAPTER XII
GELISOLS

Gelisols are a unique and distinctive soil order that is primarily associated with cold and frozen environments, making up approximately 9.7% of the world's ice-free land area. These soils are characterized by the presence of permafrost within two meters of the soil surface for a significant portion of the year. Gelisols are found in some of the coldest regions on Earth, such as the polar regions, high mountain ranges, and northern boreal forests.

One of the defining features of Gelisols is their frozen condition. Permafrost, or permanently frozen ground, plays a crucial role in shaping these soils. During the short summer thawing period, organic matter and nutrients are released from the frozen layer, leading to unique soil horizons and properties. Gelisols often have a surface layer of organic material called the "O horizon" and a horizon of mineral material mixed with organic matter known as the "A horizon."

These soils are challenging to cultivate and use for agriculture due to their frozen nature and limited thawing period. The presence of permafrost restricts root growth and water movement in the soil, making it difficult for most crops to thrive. However, Gelisols can support certain vegetation types, including cold-tolerant grasses and shrubs. In some regions, they are important for grazing livestock and wildlife habitats.

Gelisols play a critical role in the global carbon cycle. The frozen organic matter within these soils, known as peat or permafrost-affected soils, contains vast amounts of carbon that have been sequestered for thousands of years. As the climate warms and permafrost thaws, there is concern about the release of this stored carbon into the atmosphere, contributing to greenhouse gas emissions and further exacerbating climate change.

Gelisols are a unique soil order found in cold and frozen environments across the globe. Their association with permafrost and frozen conditions makes them distinct from other soil types. These soils have important ecological roles in supporting cold-adapted vegetation and storing vast amounts of carbon, but they also present challenges for agriculture and contribute to climate change concerns as permafrost thaws.

Gelisols are a type of soil found in permafrost regions, characterized by frozen conditions and cryopedogenic processes that have slowed decomposition and enhanced the sequestration of organic carbon over long periods of time (Ping et al., 2015). These soils have a high potential vulnerability to changing climatic conditions, as the organic carbon stored in permafrost-region soils may be released upon thawing of permafrost (Ping et al., 2015). Gelisols have been found to contain significant amounts of organic carbon, contributing to the global carbon cycle (Ping et al., 2015). The development of gelisols is shaped by permafrost characteristics, ice structures, and cryopedogenic processes (Ping et al., 2015).

The formation of gelisols and the accumulation of organic carbon in these soils are influenced by soil parent materials (Augusto et al., 2017). Soil parent materials play a major role in determining nutrient limitations in terrestrial ecosystems, including gelisols (Augusto et al., 2017). While nitrogen (N) limitation in gelisols is primarily driven by climate, phosphorus (P) limitation is influenced by soil parent materials (Augusto et al., 2017). The physical-chemical properties of soil parent materials, such as acidity and P richness, are tightly linked to the actual P pools of gelisols (Augusto et al., 2017).

The study of gelisols and permafrost-affected soils has advanced significantly in recent decades, despite the challenges posed by the remote and inaccessible nature of these regions (Ping et al., 2015). Efforts to understand these soils have led to increased estimates of the amount of organic carbon stored in permafrost-region soils and improved knowledge of the pedogenic processes that have built up enormous organic carbon stocks over time (Ping et al., 2015).

In the late 1980s, it was recognized that Soil Taxonomy did not adequately address soils in permafrost regions, leading to the proposal of a new order for these soils (Brevik et al., 2016). This highlights the importance of accurately classifying and understanding gelisols in order to properly manage and study these unique soil types (Brevik et al., 2016).

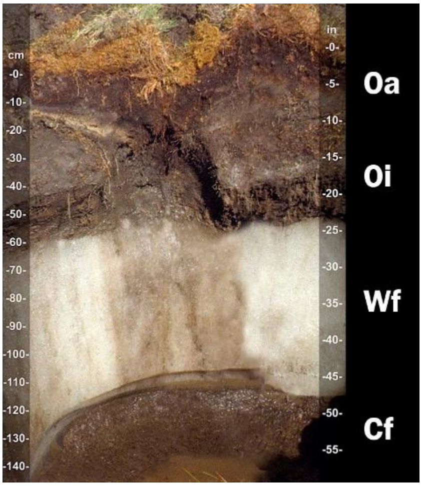


Figure 58. The Profile of Gelisols

12.1. GELISOL SUBORDER CLASSIFICATION

Gelisols, as a soil order, are further classified into several suborders based on specific characteristics and properties. These suborders help provide a more detailed understanding of Gelisols and their distribution. Gelisols are divided into 3 suborders: Histels, Turbels, and Orthels.

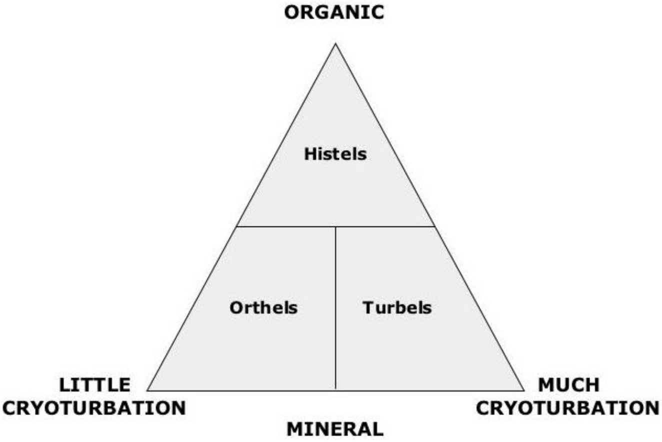


Figure 59. Suborder Diagram of Gelisols

Description:

Histels	-	Gelisols that have large quantities of organic matter
Turbels	-	Gelisols that have evidence of extensive mixing by frost action (cryoturbation)
Orthels	-	Common gelisols that don't meet criteria of the other suborder

Histel Suborder

Histel Suborder is a category within the Gelisols order of soils, and it is characterized by a significant accumulation of organic materials called histosols. These soils are commonly found in areas with cold and moist climates, such as peatlands, bogs, and wetlands, where waterlogged conditions inhibit the decomposition of organic matter.

One of the defining features of Histel Suborder soils is the presence of a thick organic horizon, often referred to as peat, which can extend several meters deep. This organic layer consists of partially decomposed plant material like mosses, grasses, and other wetland vegetation. Histel soils are typically acidic due to the accumulation of organic acids within the peat layer.

Histel soils play a crucial role in carbon storage, as they contain large amounts of organic carbon. They are important for biodiversity, serving as habitats for various plant and animal species adapted to wetland environments. In some cases, these soils have been historically used for peat harvesting, which can have environmental consequences if not managed sustainably.

Histel Suborder soils are characterized by their organic-rich horizons, often found in cold and wet environments. They are significant for carbon storage, provide important habitats for biodiversity, and have been used for peat extraction in the past. Proper management is essential to protect these valuable ecosystems.

Turbel Suborder

The Turbel Suborder is a classification within the Gelisols order of soils, and it is characterized by a unique combination of properties that distinguish it from other soil suborders. Turbel soils are typically found in cold and moist environments, often in regions with permafrost or a history of glaciation.

One of the key characteristics of Turbel soils is the presence of a permafrost layer beneath the active soil horizon. Permafrost is a layer of permanently frozen ground that can extend to varying depths depending on the local climate. This frozen layer plays a significant role in shaping the properties of Turbel soils.

Turbel soils have an active layer that thaws during the summer months, allowing for plant growth and organic matter decomposition. However, beneath this active layer, the soil remains frozen year-round. This frozen layer acts as a barrier, limiting the drainage of water from the active layer and creating waterlogged conditions in the upper soil horizon.

Because of the presence of permafrost, Turbel soils often exhibit unique soil profiles. The upper active layer can contain organic material, while the deeper frozen layer remains relatively unchanged. The interaction between the thawed and frozen layers influences the movement of water and the development of specific soil features.

Turbel Suborder soils are associated with permafrost and are typically found in cold and moist environments. They have a unique soil profile shaped by the presence of an active layer that thaws during the summer and a frozen layer beneath it. These soils are essential components of northern ecosystems and play a role in carbon storage and hydrology in these regions.

Turbel Suborder

The Turbel Suborder is a distinctive classification within the Gelisols order of soils, known for its unique characteristics primarily influenced by cold and wet environmental conditions. These soils are typically found in polar and high-altitude regions, where permafrost or seasonal frost is common.

One of the defining features of Turbel soils is the presence of permafrost, a layer of soil or sediment that remains continuously frozen for two or more years. Permafrost can extend to varying depths, depending on the local climate and geographical location. In Turbel soils, the permafrost layer typically exists beneath the active soil horizon.

The active layer in Turbel soils is the uppermost layer of soil that thaws during the warmer months of the year, allowing for plant growth and microbial activity. This layer contains organic matter, minerals, and waterlogged conditions due to limited drainage, as the underlying permafrost restricts water movement downward.

Because of the interplay between the active layer and permafrost, Turbel soils often have a unique soil profile. The upper layer can vary in thickness and composition, with organic material accumulating in some areas. Below this layer, the soil remains frozen year-round, affecting the movement of water, nutrient cycling, and overall soil development.

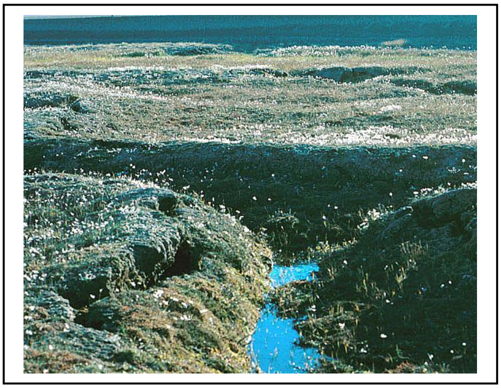
The Turbel Suborder represents a group of soils shaped by cold and wet environments, characterized by the presence of permafrost and a distinct soil profile. These soils are vital components of polar and high-altitude ecosystems, with their properties influencing plant growth, hydrology, and the storage of organic carbon.

FIGURE 60
THE LANDSCAPES OF GELISOLS

The Landscape of Gelisols

Remote Sensing observations from the ground in a patterned land, in Prudhoe Bay Alaska, reveal the characteristic polygonal fractures caused by freezing and thawing processes. In this photograph, most polygons have diameters ranging from 3 to 7 meters. Repetitive freezing and thawing cycles at the top of Gelisols associated with the formation of solid wedge-shaped ice result in the creation of microrelief with individual polygons within. The outer polygons freeze and solidify to form ridges, while the central portions become brittle.

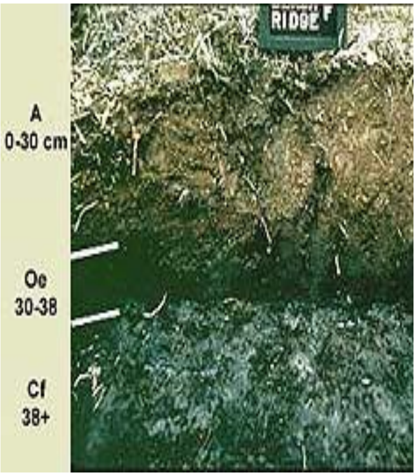
The Landscape of Gelisols



Overview of polygonal cracks in patterned ground near Prudhoe Bay, Alaska.

FIGURE 61
THE PROFILE OF ORTHELS AND FIBRISTELS

The Profile of Orthels



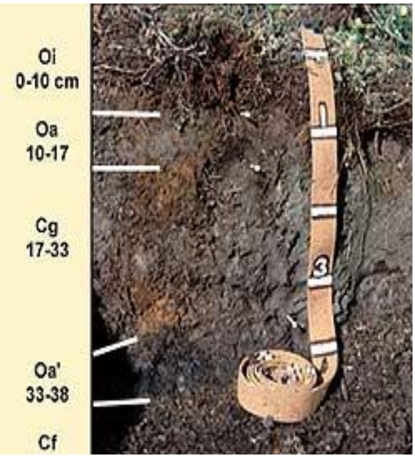
This soil originates from the coastal tundra in northern Alaska, with permafrost layers beneath 38 cm. Limited microbial activity due to cold temperatures is the primary reason for the accumulation of organic material. In this profile, the organic material accumulation is situated above the permafrost layer

The Profile of Fibristel

This soil is formed in patterned ground, near Prudhoe Bay, Alaska. Patterned ground is an informal term referring to interlocking polygonal patterns commonly found in frozen landscapes (see Example 1). This profile is located in the middle of a polygonal unit. A high percentage of organic material has accumulated in the soil due to site conditions characterized by subsidence and low microbial decomposition rates in a cold climate region.

FIGURE 62
THE PROFILE OF HISTOTURBELS AND THERMOKARST

The Profile of Histoturbel



This soil is found on a slope in Alaska. It contains a permafrost layer with a thickness of less than 38 cm. Irregular horizon boundaries are the result of cryoturbation processes. This process plays a role in preventing the merging of materials in the upper horizon with the horizon below it

The Landscape of Thermokarst

Thermokarst, which manifests as pockmarked land surfaces, is formed due to the thawing of permafrost. This phenomenon occurs following the removal of vegetation, which serves as a support. This example illustrates poor road construction planning in Alaska. Large melting ice chunks move from the roadbed, resulting in significant cavities and road damage.

12.2. THE GLOBAL DISTRIBUTION OF GELISOLS

Gelisols are a unique and specialized soil order found primarily in cold and frozen regions of the world, typically characterized by the presence of permafrost or cryoturbation. They play a crucial role in high-latitude and high-altitude ecosystems, influencing vegetation, hydrology, and carbon storage.

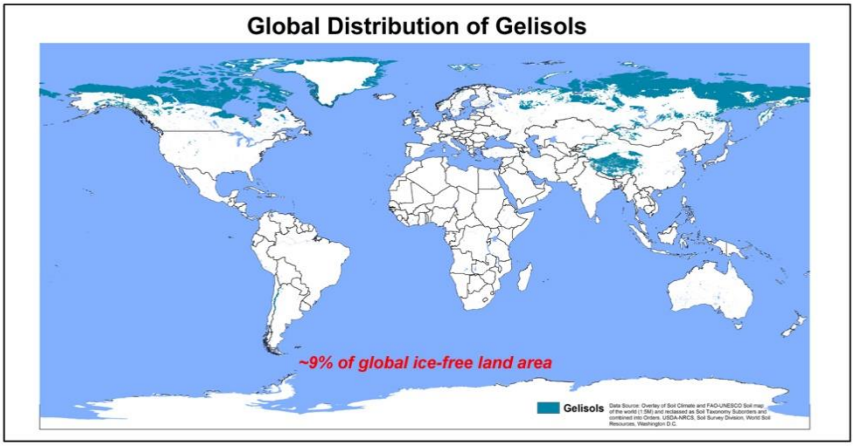


Figure 63. The Global Distribution of Gelisols

Gelisols are most abundant in polar regions, including the Arctic and Antarctic. In these extreme cold environments, permafrost is widespread, and the active layer above it is thin and seasonally frozen. Gelisols dominate the soilscape, shaping the unique polar ecosystems. It can also be found in high-altitude mountainous regions, especially in areas with persistent cold temperatures. These soils are essential for alpine and subalpine ecosystems, where they influence plant growth, water availability, and nutrient cycling. Gelisols are prevalent in northern countries such as Russia, Canada, and Alaska. The extensive permafrost in these regions contributes to the development of Gelisols, making them a significant component of the northern soil landscape.

Gelisols extend into subarctic regions, where they are found in northern parts of countries like Sweden, Finland, and Norway. These soils have a significant impact on the vegetation and hydrology of these areas. In the Southern Hemisphere, Gelisols are primarily located in Antarctica, where they play a crucial role in the unique ecosystems of the continent. They are also found in some subantarctic islands and it can be encountered in high mountain ranges around the world, such as the Andes in South America and the Himalayas in Asia. In these regions, they influence the local ecology and water resources. Gelisols are often associated with permafrost zones, which are regions where the ground remains frozen for extended periods. Permafrost areas exist in various parts of the world, and Gelisols are a characteristic soil order in these zones.

REFERENCES

Fajrina, C., Arabia, T., & Sufardi, S. (2020). Distribusi Fe- dan Al-Humus Serta C Organik Tanah pada Entisol dan Inceptisol di Lahan Kering Jantho, Kabupaten Aceh Besar. *Jurnal Ilmiah Mahasiswa Pertanian, 4*(1), 664-676. https://doi.org/10.17969/jimfp.v4i1.10203.

Lal, R. (2009). Soil Degradation as A Reason for Inadequate Human Nutrition. *Food Security, 1*(1), 45-57. https://doi.org/10.1007/s12571-009-0009-z.

Santoso, B. and Cholid, M. (2021). Pemanfaatan Biopori Serasah Daun Kering Untuk Memperbaiki Kesuburan Tanah pada Pertanaman Kemiri Sunan (*Reutealis Trisperma* (Blanco) Airy Shaw). *Buletin Tanaman Tembakau Serat & Minyak Industri, 13*(1), 14. https://doi.org/10.21082/btsm.v13n1.2021.14-25.

Surmaini, E. and Estiningtyas, W. (2020). Parameter Iklim Sebagai Indikator Peringatan Dini Serangan Hama Penyakit Tanaman. *Jurnal Sumberdaya Lahan, 12*(1), 59. https://doi.org/10.21082/jsdl.v12n1.2018.59-70.

Bockheim, J. and Munroe, J. (2014). Organic Carbon Pools and Genesis of Alpine Soils with Permafrost: A Review. *Arctic Antarctic And Alpine Research, 46*(4), 987-1006. https://doi.org/10.1657/1938-4246-46.4.987.

Herviyanti, H. (2023). Application of Local Resource-Based Amelioration Technology on The Chemical Properties of Inceptisols in Monoculture and Polyculture Cultivation Systems. *IOP Conference Series Earth and Environmental Science, 1160*(1), 012025. https://doi.org/10.1088/1755-1315/1160/1/012025.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability, 7*(5), 5875-5895. https://doi.org/10.3390/su7055875.

Barouchas, P. and Moustakas, N. (2010). Iron Oxide Distribution and Color Studies of Well-Drained Alfisols Developed on Calcareous Alluvial Deposits in Greece. Archives of Agronomy and Soil Science, 56(5), 539-550. https://doi.org/10.1080/03650340903161179.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875-5895. https://doi.org/10.3390/su7055875

Liu, C., Xia, R., Tang, W., Chen, X., Zhong, B., Liu, X., ... & Pan, G. (2022). Improved Ginseng Production Under Continuous Cropping Through Soil Health Reinforcement and Rhizosphere Microbial Manipulation With Biochar: A Field Study of Panax Ginseng from Northeast China. *Horticulture Research, 9*. https://doi.org/10.1093/hr/uhac108.

Ramu, K., Sahrawat, K., & Wani, S. (2012). Fertilizer-Induced Nitrous Oxide Emissions from Vertisols and Alfisols During Sweet Sorghum Cultivation in The Indian Semi-Arid Tropics. *The Science of The Total Environment, 438*, 9-14. https://doi.org/10.1016/j.scitotenv.2012.08.005.

Subrahmanyam, G., He, J., Zheng, Y., Archana, G., He, J., & Liu, Y. (2014). Response of Ammonia-Oxidizing Microbes to The Stresses of Arsenic and Copper in Two Acidic Alfisols. *Applied Soil Ecology, 77*, 59-67. https://doi.org/10.1016/j.apsoil.2014.01.011.

Widijanto, H., Muliawati, E., Favreta, V., & Hidayanto, M. (2021). The Growth Response of Banana CV. Barangan (*Musa Acuminata* L.) from Tissue Culture with Organic Manure and Arbuscular Mycorrhizal Fungi. *Indian Journal of Agricultural Research*, (Of). https://doi.org/10.18805/ijare.a-633

Barouchas, P. and Moustakas, N. (2010). Iron Oxide Distribution and Color Studies of Well-Drained Alfisols Developed on Calcareous Alluvial Deposits in Greece. Archives of Agronomy and Soil Science, 56(5), 539-550. https://doi.org/10.1080/03650340903161179.

Guerra, M., Walker, E., Jones, C., Paskewitz, S., Cortinas, M., Stancil, A., … & Kitron, U. (2002). Predicting The Risk of Lyme Disease: Habitat Suitability for Ixodes Scapularis in The North Central United States. *Emerging Infectious Diseases, 8*(3), 289-297. https://doi.org/10.3201/eid0803.010166.

Klemedtsson, L., Arnold, K., Weslien, P., & Gundersen, P. (2005). Soil CN Ratio as A Scalar Parameter To Predict Nitrous Oxide Emissions. *Global Change Biology, 11*(7), 1142-1147. https://doi.org/10.1111/j.1365-2486.2005.00973.x.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability, 7*(5), 5875-5895. https://doi.org/10.3390/su7055875.

Liu, C., Xia, R., Tang, W., Chen, X., Zhong, B., Liu, X., … & Pan, G. (2022). Improved Ginseng Production Under Continuous Cropping Through Soil Health Reinforcement and Rhizosphere Microbial Manipulation with Biochar: A Field Study of Panax Ginseng from Northeast China. *Horticulture Research, 9*. https://doi.org/10.1093/hr/uhac108.

Ramu, K., Sahrawat, K., & Wani, S. (2012). Fertilizer Induced Nitrous Oxide Emissions from Vertisols and Alfisols During Sweet Sorghum Cultivation in The Indian Semi-Arid Tropics. *The Science of The Total Environment, 438,* 9-14. https://doi.org/10.1016/j.scitotenv.2012.08.005.

Subrahmanyam, G., He, J., Zheng, Y., Archana, G., He, J., & Liu, Y. (2014). Response of Ammonia-Oxidizing Microbes to The Stresses of Arsenic and Copper in Two Acidic Alfisols. *Applied Soil Ecology, 77*, 59-67. https://doi.org/10.1016/j.apsoil.2014.01.011.

Widijanto, H., Muliawati, E., Favreta, V., & Hidayanto, M. (2021). The Growth Response of Banana CV. Barangan (*Musa Acuminata* L.) from Tissue Culture with Organic Manure and Arbuscular Mycorrhizal Fungi. *Indian Journal of Agricultural Research*, (Of). https://doi.org/10.18805/ijare.a-633.

Chowdhury, R. (2006). Driving Forces of Tropical Deforestation: The Role of Remote Sensing and Spatial Models. *Singapore Journal of Tropical Geography, 27*(1), 82-101. https://doi.org/10.1111/j.1467-9493.2006.00241.x.

Ikitoo, E., Okalebo, J., & Othieno, C. (2011). Towards Sustainable Land Use in Vertisols in Kenya: Challenges and Opportunities., 661-675. https://doi.org/10.1007/978-90-481-2543-2_67.

Kurtzman, D., Baram, S., & Dahan, O. (2016). Soil–Aquifer Phenomena Affecting Groundwater Under Vertisols: A Review. Hydrology and *Earth System Sciences, 20*(1), 1-12. https://doi.org/10.5194/hess-20-1-2016.

Pal, D., Wani, S., & Sahrawat, K. (2012). Vertisols of Tropical Indian Environments: Pedology and Edaphology. *Geoderma*, 189-190, 28-49. https://doi.org/10.1016/j.geoderma.2012.04.021

Panichini, M., Matus, F., Mora, M., Godoy, R., Bolan, N., Rumpel, C., … & Borie, F. (2012). Carbon Distribution in Top- And Subsoil Horizons of Two Contrasting Andisols Under Pasture or Forest. *European Journal of Soil Science, 63*(5), 616-624. https://doi.org/10.1111/j.1365-2389.2012.01488.x.

Rust, B. and Nanson, G. (1989). Bedload Transport of Mud as Pedogenic Aggregates in Modern and Ancient Rivers. *Sedimentology, 36*(2), 291-306. https://doi.org/10.1111/j.1365-3091.1989.tb00608.x.

Oliveira, A., Ker, J., Silva, I., Oliveira, A., & Neves, A. (2010). Spodosols Pedogenesis under Barreiras Formation and Sandbank Environments in The South of Bahia. *Revista Brasileira De Ciência Do Solo, 34*(3), 847-860. https://doi.org/10.1590/s0100-06832010000300026.

Silva, G., Camêlo, D., Corrêa, M., Júnior, V., Filho, M., & Filho, J. (2019). Pedogenesis on Coastal Tablelands Area with Low Range Altimetry in Paraíba State. *Revista Caatinga, 32*(2), 458-471. https://doi.org/10.1590/1983-21252019v32n219rc.

Yli-Halla, M., Mokma, D., Wilding, L., & Drees, L. (2008). Formation of A Cultivated Spodosols in East-Central Finland. *Agricultural and Food Science, 15*(1), 12. https://doi.org/10.2137/145960606777245560.

Subagyo, H., N. Suharta, dan A.B. Siswanto. 2004. Tanah-Tanah Pertanian di Indonesia. Dalam A. Adimihardja, L.I. Amien, F. Agus, D. Djaenudin (Ed.). Sumberdaya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian dan Pengembangan Tanah Agroklimat, Bogor. Hal 21–66.

Achieng, J., Ouma, G., Odhiambo, G., & Muyekho, F. (2010). Effect of Farmyard Manure and Inorganic Fertilizers on Maize Production On Alfisols And Ultisols In Kakamega, Western Kenya. *Agriculture and Biology Journal of North America, 1*(4), 430-439. https://doi.org/10.5251/abjna.2010.1.4.430.439

Purwanto, S., Gani, R., & Suryani, E. (2020). Characteristics of Ultisols Derived from Basaltic Andesite Materials and Their Association with Old Volcanic Landforms in Indonesia. *Sains Tanah - Journal of Soil Science And Agroclimatology, 17*(2), 135. https://doi.org/10.20961/stjssa.v17i2.38301.

George, T., Turner, B., Cade-Menun, B., & Richardson, A. (2006). Depletion of Organic Phosphorus from Oxisols in Relation to Phosphatase Activities in The Rhizosphere. *European Journal of Soil Science, 57*(1), 47-57. https://doi.org/10.1111/j.1365-2389.2006.00767.x

McDowell, M., Bruland, G., Deenik, J., & Grunwald, S. (2012). Effects of Subsetting by Carbon Content, Soil Order, and Spectral Classification on Prediction of Soil Total Carbon with Diffuse Reflectance Spectroscopy. *Applied and Environmental Soil Science, 2012*, 1-14. https://doi.org/10.1155/2012/294121.

Padmanabhan, E., Eswaran, H., & Mermut, A. (2011). Classifying Soils At The Ultimate Stage Of Weathering In The Tropics. *Journal of Plant Nutrition and Soil Science, 175*(1), 86-93. https://doi.org/10.1002/jpln.201000348.

Yang, X., Post, W., Thornton, P., & Jain, A. (2013). The Distribution of Soil Phosphorus for Global Biogeochemical Modeling. *Biogeosciences, 10*(4), 2525-2537. https://doi.org/10.5194/bg-10-2525-2013.

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Dani Lukman Hakim is a highly accomplished author and lecturer in the field of Agribusiness. With an extensive educational background and years of teaching experience, he has made significant contributions to the academic community. He currently serves as a lecturer in the Agribusiness study program at President University, Indonesia. He has been actively involved in teaching since 2005, dedicating himself to imparting knowledge and shaping the minds of future agribusiness professionals.

Dani Lukman Hakim embarked on his academic journey by pursuing his undergraduate studies at the Agriculture Faculty of Padjadjaran University and participated in an undergraduate sandwich program at Fachhochschule Erfurt in Germany. He pursued a Doctorate Program at Gadjah Mada University in Indonesia through an acceleration program. He participated in a doctoral sandwich program at Idaho University in the United States.

Dani Lukman Hakim's educational background has provided him with a solid foundation in various disciplines related to agribusiness. His areas of specialization include Fundamentals of Soil Science, Fundamentals of Agricultural Science, Sustainable Agriculture and Development, Rural Development and Sustainability, Remote Sensing and Spatial Analysis, and Agribusiness Marketing.

Beyond his academic pursuits, Dani Lukman Hakim actively engages in consulting activities, collaborating with private and state institutions. This involvement allows him to bridge the gap between academia and industry, applying his knowledge and expertise to real-world challenges.

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