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Problems Associated with Physical and Chemical Properties of Vertisols and Management Options in Agriculture - A Review

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Abstract

Vertisols are a group of heavy-textured soils which occur extensively in the tropics, subtropics and warm temperate zones and are known as Dark Clays, Black Earths, Black Cotton soils, Dark Cracking soils, Grumusols and Regurs in other classification systems. Approximately 310 million ha of these soils in Asia (mostly in India), in America (mostly in the United States of America, Venezuela, and Argentina), in Australia, and in the continent of Africa. Vertisols are often formed from weathered volcanic ash, basalt, or other fine-grained materials that contain a high proportion of clay minerals. These parent materials undergo weathering and transformation processes over time, resulting in the development of Vertisols with their characteristic high clay content. Vertisols are a unique type of soil known for their high clay content with clay particles making up a significant proportion of their composition, typically exceeding 30%, Vertisols exhibit distinct characteristics that have both advantages and challenges for agricultural practices. The shrink-swell behavior refers to the volume changes that occur in Vertisols as they undergo wetting and drying cycles. Vertisols, a type of soil characterized by their high clay content, possess a remarkable water-holding capacity. This unique characteristic makes Vertisols highly valuable for agricultural practices, particularly in areas with variable rainfall patterns. They constitute a considerable agricultural potential but adapted management like cop rotation, surface drainage, tillage fertilization early planting and cropping system are a precondition for soil management and sustained crop production.

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Cracks, Clay content, Organic matter, Nutrient and vertisols.

Introduction

Vertisols, characterized by their high clay content and unique properties, are found in various climate regions around the world. Approximately 310 million ha of these soils in Asia (mostly in India), in America (mostly in the United States of America, Venezuela, and Argentina), in Australia, and in the continent of Africa. Vertisols occur extensively in several countries in Africa under arid, semi-arid, and humid climates, and have an agroecological potential for food production well above their present level of use. According to Wubetu (2017), there are approximately 104 million ha of Vertisols and vertic soils in Burkina Faso, Niger, Nigeria, Chad, Sudan, Ethiopia, Somalia, Kenya, Burundi, Malawi, Zambia, Zimbabwe, and Botswana. Some small areas occur in other countries of Africa, and altogether about 30% of the world's Vertisols are located in Africa.

Vertisols are a highly productive group of soils and contain at least 30% clay, and the dominant clay mineral is usually one of the smectite groups. These soils are generally 60 cm deep or more. Vertisols are therefore able to retain considerable amounts of available water in the soil profile. Due to the nature of the dominant clay mineral, they exhibit shrinking and swelling properties, and are highly erodiable. Their physical properties make them difficult to handle with the nature of heavy soils and are difficult to cultivate; further, some exhibit a 'gilgai' formation, and therefore the preparation of the seedbed on these soils presents many difficulties. Due to their low terminal water intake rates, they easily get waterlogged during the rainy season (Kögel-Knabner and Amelung, 2021).

In agricultural productivity, Vertisols offer favorable conditions for crop cultivation (Millán, 2012). Their inherent fertility, combined with the ability to retain moisture and nutrients, provides favorable environment for plant growth. This makes Vertisols suitable for a wide range of crops, including cereals, legumes, oilseeds, and vegetables (Sione *et al.,* 2017). The cohesive nature of Vertisols, attributed to their high clay content, makes them less prone to erosion compared to other soil types (Torri *et al.,* 2013). This characteristic helps protect against soil degradation and loss of valuable topsoil, contributing to soil conservation and long-term sustainability. The high clay content and unique properties of Vertisols make them valuable for agriculture, providing opportunities for crop cultivation and contributing to food production (Pierre *et al.,* 2019). However, the management of Vertisols presents challenges due to their shrink-swell behavior and compaction tendencies (Paul *et al.,* 2021). Understanding the occurrence and distribution of Vertisols is crucial for implementing appropriate soil management practices and maximizing their agricultural potential. The management of Vertisols soil is of utmost importance for maximizing agricultural productivity, preserving soil health, and promoting sustainable land use by implementing appropriate management practices (Al-Shatib *et al.,* 2020).

Occurrence and Distribution of Vertisols

Accurate statistics on the occurrence, distribution and land area occupied by Vertisols in Africa are not known and it is considered important that more realistic data should be available.

There have been several estimates (Tamfuh *et al.,* 2018) of the areas occupied by Vertisols in Africa and these range from 100 million to 118 million hectares or about 35 percent of the world's Vertisols. When more detailed information is available, the total area could reach or even exceed 120 million hectares. The soils occur in several climatic zones ranging from arid to humid however, over 50 percent of them occur in the sub-humid to semi-arid climatic zone which occurs from West, Central, Eastern to Southern Africa in a rainfall regime of between 200 and 800 mm per annum which is either modal or bimodal in different regions of the continent (Ahmad, 1996).

Parent Materials

The parent materials of Vertisols soil can vary, but they are typically derived from clay-rich materials. Vertisols are often formed from weathered volcanic ash, basalt, or other fine-grained materials that contain a high proportion of clay minerals (Stoops *et al.,* 2018). These parent materials undergo weathering and transformation processes over time, resulting in the development of Vertisols with their characteristic high clay content. Volcanic ash deposits are a common parent material for Vertisols. Volcanic ash is composed of fine particles that are rich in minerals such as smectite, which is a type of clay mineral known for its high swelling capacity. The weathering of volcanic ash over time leads to the formation of Vertisols with their unique properties basaltic parent materials can also give rise to Vertisols. Basalt is a volcanic rock that contains minerals such as montmorillonite, another type of clay mineral commonly found in Vertisols (Ahmad, 1983). The weathering of basaltic parent materials, combined with the accumulation of organic matter and other factors, contributes to the development of Vertisols. Other clay-rich materials, such as alluvial deposits or sedimentary rocks with high clay content, can also serve as parent materials for Vertisols. These materials undergo weathering and physical processes that result in the formation of Vertisols with their characteristic clayey texture and high water-holding capacity. It is important to note that the specific parent materials of Vertisols can vary depending on the geographical location and geological history of the area. The composition and properties of the parent materials influence the characteristics of the resulting Vertisols, including their clay content, water-holding capacity, and nutrient retention capacity (Carter, 2002).

Physical Characteristics of Vertisols

Physically, Vertisols are dark in color and have a heavy texture due to their high clay content. They are well-structured soils that can retain water well, but their swelling and shrinking behavior can pose challenges for building infrastructure or farming some physical characteristics are described below.

High clay content

Vertisols are a unique type of soil known for their high clay content with clay particles making up a significant proportion of their composition, typically exceeding 30%, Vertisols exhibit distinct characteristics that have both advantages and challenges for agricultural practices. One of the key features of Vertisols is their soil structure. The high clay content gives Vertisols a dense and compact structure, often referred to as a "crumb" or "blocky" structure (Pierre *et al.,* 2019). The clay particles, with their small size and flat shape, stack together tightly, providing stability to the soil and helping to resist erosion. This structural stability is particularly beneficial in areas prone to heavy rainfall or strong winds, as it helps prevent soil erosion and loss of valuable topsoil. Another important aspect of high clay content in Vertisols is their water-holding capacity (Ruan *et al.,* 2021). Clay particles have a large surface area and can hold onto water through a process called adsorption. This means that Vertisols can retain water for longer periods, making them more resilient to drought conditions. The ability to hold water can be advantageous for crop production, as it provides a reservoir of moisture that plants can access during dry spells. However, it is crucial to manage irrigation carefully to prevent water logging, as excessive moisture can lead to poor aeration and root oxygen deprivation. The high clay content in Vertisols also contributes to their nutrient retention capacity (Stoops *et al.,* 2018). Clay particles have a high cation exchange capacity (CEC), which allows them to attract and hold onto positively charged nutrient ions. This characteristic helps prevent nutrient leaching and makes nutrients more available to plants over time. However, it is important to manage nutrient application carefully, as the high CEC can also lead to nutrient imbalances if not properly monitored and adjusted. While the high clay content in Vertisols provides several advantages, it also presents challenges for agricultural practices. The sticky and plastic nature of clay soils can make them difficult to work with, especially when they are wet. This can pose challenges for field operations such as planting, tillage, and harvesting. Proper soil management practices, including timing fieldwork during optimal soil moisture conditions and using appropriate machinery, can help overcome these challenges and ensure efficient and effective operations (Torri *et al.*, 2013).

Shrink-swell behavior

Vertisols are a unique type of soil known for their distinctive shrink-swell behavior. This behavior is a result of the high clay content and specific mineralogy found in Vertisols. The shrink-swell behavior of Vertisols can have significant implications for agricultural practices (Al-Shatib *et al.,* 2022). The shrink-swell behavior refers to the volume changes that occur in Vertisols as they undergo wetting and drying cycles. When Vertisols are exposed to moisture, the clay particles absorb water and expand, causing the soil to swell. Conversely, during dry periods, the clay particles lose moisture and contract, leading to soil shrinkage. This shrink-swell behavior can have both advantages and challenges for agriculture. One advantage is that the shrink-swell behavior allows Vertisols to act as natural reservoirs of moisture (Paul *et al.,* 2021). During wet periods, the soil swells and absorbs water, which can be beneficial for crop growth. The expanded clay particles create pore spaces that can hold water, making it available to plants during dry spells. This moisture availability can help sustain plant growth and reduce the reliance on irrigation in certain situations. However, the shrink-swell behavior also poses challenges for agricultural practices. When the soil swells, it can lead to the formation of large cracks upon drying, which can affect root penetration and water infiltration. The shrink-swell behavior can cause soil compaction and affect the porosity of the soil. This can impact water movement, nutrient availability, and overall crop productivity. The challenges associated with the shrink-swell behavior of Vertisols can be addressed through proper soil management practices (Ravansari *et al.*, 2020).

Deep cracks

Vertisols, a type of soil characterized by their high clay content, are known for their tendency to develop deep cracks. These cracks are a result of the unique shrink-swell behavior exhibited by Vertisols, which is influenced by the clay minerals present in the soil. The deep cracks in Vertisols occur during dry periods when the soil undergoes shrinkage due to the loss of moisture. As the clay particles contract, they create gaps and fissures in the soil, resulting in the formation of deep cracks that can extend several centimeters or even meters into the ground. The development of deep cracks in Vertisols can have both advantages and challenges for agricultural practices (Somasundaram *et al.,* 2018). On one hand, these cracks can improve soil aeration and water infiltration when they fill with water during rainy periods. This can be beneficial for plant roots, as it allows for better access to oxygen and water. However, the presence of deep cracks in Vertisols can also pose challenges for farmers. The cracks can lead to increased water loss through evaporation, as the exposed soil surface allows for rapid moisture evaporation. This can result in reduced soil moisture availability for plant uptake, especially during dry periods. Additionally, the deep cracks can make field operations more challenging. Planting seeds or transplanting seedlings may be difficult due to the uneven soil surface caused by the cracks. The cracks can also interfere with the movement of machinery, making it harder to perform tasks such as plowing or harvesting (Yang *et al.,* 2018).

Water holding capacity

Vertisols, a type of soil characterized by their high clay content, possess a remarkable water-holding capacity. This unique characteristic makes Vertisols highly valuable for agricultural practices, particularly in areas with variable rainfall patterns. The high clay content in Vertisols contributes to their water-holding capacity. Clay particles have a large surface area and possess the ability to attract and hold water molecules through a process called adsorption. This means that Vertisols can retain water for extended periods, making them more resilient to drought conditions. The water-holding capacity of Vertisols offers several advantages for agricultural production (Çakir, 2019). Firstly, it provides a natural reservoir of moisture that crops can access during dry spells. The clay particles in Vertisols create pore spaces that can hold water, ensuring a steady supply of moisture to plant roots. This can help sustain plant growth and reduce the reliance on irrigation, leading to water conservation and potentially lower irrigation costs for farmers. The water-holding capacity of Vertisols contributes to improved soil fertility and nutrient availability. The clay particles in Vertisols have a high cation exchange capacity (CEC), which allows them to attract and retain positively charged nutrient ions. This helps prevent nutrient leaching and makes nutrients more available to plants over time. The ability of Vertisols to retain water also facilitates the dissolution and transport of essential nutrients, ensuring their accessibility to plant roots (Al-Shatib *et al.,* 2020).

Chemical Proporties of Vertisols

From a chemical perspective, Vertisols are typically high in base cations like calcium, magnesium, and potassium. They also have a high cation exchange capacity, which means they can hold and release nutrients effectively, making fertile soils for agriculture. Vertisols are chemically very fertile in the natural state and this particularity makes them very attractive for agricultural purposes some chemical properties are described below

Soil reaction (pH)

The organic matter content of Vertisols soil can vary depending on factors such as climate, vegetation cover, and management practices. Generally, Vertisols have the potential to contain a significant amount of organic matter due to their high clay content and the ability to retain nutrients. As in the case of physical properties, the chemical nature of Vertisols occurring in diverse environments is somewhat similar. The Vertisols occurring in India, Australia, Sudan, Ethiopia and other parts of Africa generally have soil pH ranging between 7.5 and 8.5 in the soil profile (Virmani *et al.,* 1988). Factors which contribute to high soil pH are the presence of $CaCO3$ and high contents of bases, especially calcium and magnesium, in the profile. The high pH of Vertisols favours gaseous loss of ammonia when urea or ammonium fertilizers are applied to the surface. In tropical areas where the soils have either been irrigated or are located in the valleys, the soil reaction may be as high as 9.5 in the surface soil as a consequence of accumulation of exchangeable sodium; in conjunction with their high contents of clay, usually montmorillonite, this has disastrous effects on soil structure (Ahmad, 1983).

Calcium carbonate accumulation

Vertisols soil may accumulate calcium carbonate (lime) deposits. This can affect soil pH and nutrient availability. The accumulation of calcium carbonate in Vertisols can lead to the formation of hardpans or calcareous layers. These layers can restrict root growth, limit water movement, and affect soil drainage. The presence of calcareous layers can pose challenges for agriculture, as it can impede root penetration and nutrient uptake by crops. It is important to consider the presence of calcium carbonate and its impact on soil chemistry when formulating fertilizer recommendations and adjusting soil amendments (Alonso and Wright, 2010).

Cation Exchange Capacity (CEC)

The Cation Exchange Capacity (CEC) of Vertisols soil is typically high due to its high clay content. CEC refers to the soil's ability to retain and exchange cations (positively charged ions) such as calcium ($Ca2^+$), magnesium ($Mg2^+$), potassium (K^+), and ammonium ($NH4^+$). The high clay content in Vertisols soil provides a large surface area for cation exchange, allowing the soil to hold onto and release nutrients as needed by plants (Torri *et al.,* 2013).

This is beneficial for agriculture as it helps to retain essential nutrients and prevent leaching. The specific CEC value of Vertisols soil can vary depending on factors such as clay mineralogy, organic matter content, and soil management practices.

Generally, Vertisols soil has a CEC ranging from moderate to high, often exceeding to 20 (cmol $kg^{-1)}$. Understanding the CEC of Vertisols soil is important for nutrient management in agriculture. It helps determine the soil's nutrient-holding capacity and guides fertilizer recommendations (Carter, 2002).

Low organic matter content

Vertisols soil can have relatively low organic matter content compared to other soil types. The low organic matter content in Vertisols is primarily due to factors such as climate, vegetation cover, and management practices. The high clay content of Vertisols soil can make it challenging for organic matter to decompose and incorporate into the soil (Pierre *et al.,* 2019).

The shrink-swell behavior of Vertisols can lead to the burial of organic matter deeper into the soil profile, making it less accessible for decomposition. Low organic matter content in Vertisols soil can have implications for soil fertility, nutrient availability, and overall soil health. Organic matter plays a crucial role in improving soil structure, water-holding capacity, nutrient retention, and microbial activity. It also contributes to the release of essential nutrients for plant uptake (Virmani *et al.,* 1988).

Management Options of Vertisols Soil

Early planting

Early planting in Vertisols soil can offer several advantages for crop production. However, it is important to consider the specific characteristics of Vertisols and implement appropriate management practices to ensure successful early planting. One advantage of early planting in Vertisols is the higher water-holding capacity of these soils (Srinivasarao *et al.,* 2014). Vertisols can retain moisture for extended periods due to their high clay content, which can be beneficial for early-planted crops, especially during dry spells. Early planting allows crops to take advantage of the moisture stored in the soil, providing a head start for germination and establishment (Triplett and Dick, 2008).

Cropping systems

Vertisols should receive particular care with regard to the selection of a cropping system. For instance, suitable crop rotation is an important part of land management. Moreover, crop selection should take into consideration the provision of a good dense vegetation cover.

The seeding rate also needs to be taken into account as an essential aspect of the technology (Srinivasarao *et al.,* 2014). Further, it is important that plant residue should be incorporated in the soil to increase the organic-matter content and to allow better root penetration. One of the difficulties in the management of Vertisols is that the plant roots are not able to penetrate the soil and absorb the maximum amount of moisture and nutrients, even if the soil is very deep (Sione *et al.,* 2017).

Fertilization

Vertisols generally give a good response to nitrogen fertilizer and the dissemination of the nutrients in the Soil is relatively slow, it is recommended that the amount of nitrogen should be split into two or three applications to obtain the maximum benefit.

Phosphorus also gives good results, but may only need to be applied once, either before or with seeding. Alternatively it might be applied once every two or three years, depending on its availability in the soil.

Most Vertisols are already rich in potash, so this element is not applied in most cases, unless its level decreases or the cropping system includes some potash-sensitive crop. Micronutrients might be needed in some cases, but deficiencies can easily be detected and tests can be made accordingly (Syers *et al.,* 2001).

Tillage

Vertisols should receive particular care with regard to soil tillage and cultivation should take place at the appropriate time and with the appropriate moisture content. In contrast with so many other soils, Vertisols are not easy to cultivate under very dry or very wet conditions.

Table.1 List.of countries in Africa with Vertisols and vertic soil groups by climatic zones

Humid and subhumid	Semi-arid	Arid
Cameroon	Botswana	Chad
Ethiopia	Burkina Faso	Somalia
Sudan	Burundi	Sudan
Zaire	Chad	
Mozambique	Ethiopia	
Angola	Kenya	
Uganda	Malawi	
Dahomey	Niger	
Togo	Nigeria	
Shana	Sudan	
Ivory Coast	South Africa	
	Zambia	
	Zimbabwe	
	Senegal	
	Tanzania	
	Uganda	
	Ghana	

Source: Kanwar and Virmani (1986).

Fig.1 Distribution of vertisols

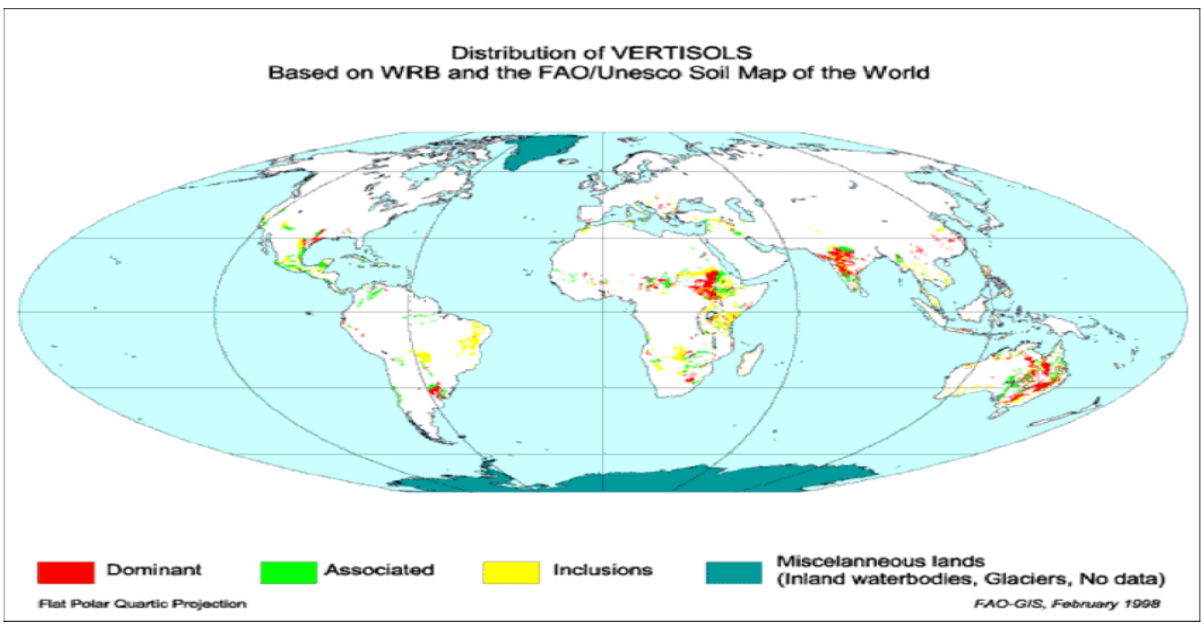

Fig.2 Vertisols soil profile

Ploughing should be as shallow as possible and deep ploughing should only be applied for annual crops once every 3 to 4 years. Zero tillage is suitable in most cases, and is highly recommended in citrus orchards or other tree plantations where the rooting system is very shallow. Ploughing should be done immediately after harvesting the wheat - to conserve the remaining moisture in the soil on the one hand, and to avoid the hardening of the topsoil due to drought on the other (Millán, 2012).

Surface drainage

Even under severe drought conditions Vertisols may become waterlogged after heavy rain unless surface drainage is properly maintained. Irregular microtopography leads to irregularity in moisture distribution, and in this case it is necessary to use the grader blade or some other suitable technique to obtain a regular slope. This operation should be repeated whenever necessary, since this irregular microrelief forms normally even on a flat topography due to the swelling and shrinking of these soils every year in response to the sequence of the wet and dry seasons (Ravansari *et al.,* 2020).

Crop rotations

Crop rotation is an essential management practice for Vertisols that can help improve soil health, nutrient cycling, pest and disease control, and overall crop productivity (Kumar *et al.,* 2020). By strategically rotating crops, farmers can optimize the use of nutrients, break pest and disease cycles, and reduce the risk of soil degradation. One of the primary benefits of crop rotation in Vertisols is the improvement of soil fertility (Triplett and Dick, 2008). Different crops have varying nutrient requirements and uptake patterns. By rotating crops with different nutrient needs, farmers can prevent nutrient depletion and ensure balanced nutrient availability in the soil. For example, leguminous crops like soybeans or peas can fix atmospheric nitrogen, enriching the soil with this essential nutrient for subsequent crops. When planning crop rotations in Vertisols, it is important to consider the specific characteristics of the soil. The high clay content and water-holding capacity of Vertisols can influence crop selection and rotation patterns. Crops that are well-adapted to Vertisols' characteristics, such as their high clay content and water-holding capacity, should be prioritized (Srinivasarao *et al.,* 2014).

Recommendations

Vertisols occur in many climates approximately 310 million ha of these soils in Asia (mostly in India), in America (mostly in the United States of America, Venezuela, and Argentina), in Australia, and in the continent of Africa. Vertisols occur extensively in several countries in Africa under arid, semi-arid, and humid climates, and have an agroecological potential for food production well above their present level of use. There are approximately 104 million ha of Vertisols and vertic soils in Burkina Faso, Niger, Nigeria, Chad, Sudan, Ethiopia, Somalia, Kenya, Burundi, Malawi, Zambia, Zimbabwe, and Botswana. Some small areas occur in other countries of Africa, and altogether about 30% of the world's Vertisols are located in Africa. The parent materials of Vertisols soil can vary, but they are typically derived from clay-rich materials. Vertisols are often formed from weathered volcanic ash, basalt, or other fine-grained materials that contain a high proportion of clay minerals. Vertisols constitute a soil class easily identifiable by their heavy clayey texture, their dark colour and their unique physical attributes as stress cracking in the dry season, surface ponding in the rainy season, slickensides. Vertisols are heavy clay soils that occur mainly in the intertropical zone with contrasting wet and humid seasons. Vertisols, a type of soil is characterized by high clay content, present unique challenges and opportunities for agricultural management. These soils, often found in regions with distinct wet and dry seasons, are known for their high fertility but also for their tendency to crack and swell, which can pose significant problems for agricultural operations. They constitute a considerable agricultural potential but adapted management is a precondition for sustained production. Their high fertility and water-holding capacity can support high crop yields when managed correctly. The key is to implement management strategies that mitigate the challenges and leverage the benefits of these unique soils.

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