Soil Particle Size Analysis: Methods, Classification, Models, and Their Implications for Soil Health

Ganesh Parmar[1], Gaurang Chudasama[2*], Radha Rajput[3], Pravinkumar Rajgadhi[4], Shreyas Bhatt[5]

[1]Department of Life Sciences, Hemchandracharya North Gujarat University, Patan, 384 265, India.
Email: ganeshmicro@ngu.ac.in ; Orcid id: 0009-0001-6616-8653
[2*]Narmada College of Science & Commerce, Zadeshwar-Bharuch, 392011, India.
Email: dr.grchudasama@gmail.com, Orcid id: 0009-0001-1593-3239
[3]Depatment of Chemistry, Veer Narmad South Gujarat University, Surat, 395007, India.
Email: radharajpoot1707@gmail.com ; Orcid id: 0009-0008-3778-6920
[4]Narmada College of Science & Commerce, Zadeshwar-Bharuch, 392011, India. Email: ncscpjr@gmail.com
[5]Department of Life Sciences, Hemchandracharya North Gujarat University, Patan, 384 265, India.
Email: sabhatt@ngu.ac.in, Orcid id: 0000-0001-6556-279
*Corresponding Author: Dr.Grchudasama@Gmail.Com, Orcid id: 0009-0001-1593-3239

Abstract
Soil particle size analysis is a crucial test used to classify soils and predict their behavior. This review paper aims to provide an in-depth understanding of the method for analyzing soil particles, including its principles, concepts, particle distribution, and the relationships between them. It also discusses the importance of accuracy, precision, and the use of reference materials in soil particle size analysis. The test of soil particle size analysis involves determining the relative proportion by weight of different soil particles in a soil sample. This information is essential for soil classification, as it helps to identify the composition and characteristics of the soil. By understanding the particle size distribution, scientists and engineers can better predict the behavior of soils in various applications, such as agriculture, geotechnical engineering, and environmental sciences. Accuracy and precision are critical factors in soil particle size analysis. Accuracy refers to how close the measured values are to the true values, while precision refers to the consistency and reproducibility of the measurements. Achieving both accuracy and precision in soil particle size analysis is essential to ensuring reliable and meaningful results. It involves using appropriate techniques, standardized procedures, and quality control measures. Reference materials play a vital role in soil particle size analysis. These materials are used to calibrate and validate the analytical methods, ensuring the accuracy and reliability of the results. Reference materials are typically well-characterized soils with known particle size distributions. By comparing the results obtained from the analysis of the reference materials with the known values, the accuracy of the analytical method can be assessed, and any necessary adjustments can be made.
In conclusion, this review paper focuses on the method of analyzing soil particles, covering principles, concepts, particle distribution, and the relationships between them. It emphasizes the importance of accuracy, precision, and the use of reference materials in soil particle size analysis. By understanding the impact of soil physicochemical parameters, this test provides valuable information for soil classification and predicting soil behavior in various applications.

Keywords: Soil particle size, Soil classification, Soil health indicator, organic matter, organic carbon

Introduction

A coherent body with an easily distinct surface defines a particle. Particles may be made up of a single material with uniform properties or of smaller particles bound together, each of whose properties may be very dissimilar. To a greater or lesser extent, the particles are byproducts of the specific conditions under which soils are formed. For the determination of soil particle size, there are currently 400 reported techniques (Barth & Sun, 1989). Soils may contain particles from ≤1 m in a maximum dimension to ≥ 1 mm, i.e., a size ratio of 1,000,000:1 or more. For the larger particles, a basic measurement of size is the distance between the largest points on the particle, which is visible to the human eye. Most soil scientists are interested in the percentage (often expressed as a weight percent) of particles falling inside a certain size class, which is indicated by an upper and lower limit (e.g., 63–212 mm). Each class of size corresponds to a grade and is typically distinguished by name, such as clay, silt, or sand (Wentworth, 1922). Atterberg's work shows soil classification according to different soil particle sizes (Atterberg, 1916). Bowlder: Bowlders are large, round rocks that have been worn smooth by moving water and other forces. They are typically larger than cobbles, which are smaller, round rocks. The word "bowlder" may be related to the English word bellow, which means to make a loud, low noise. This suggests that the word "bowlder" may have come from the sound of rocks rolling and rumbling (Arriaga et al., 2006; Geology, 1922; Wentworth, 1922; Yingst et al., 2016).

Cobble: Cobbles and cobblestones are both terms for small, rounded stones that are smaller than boulders and larger than pebbles. The word comes from the German word cob, which means a rounded hump or knob. This suggests that cobbles and cobblestones are named after their shapes.

Pebble: This term is very ancient and is used for rounded, transported rock fragments smaller than cobbles. Pebble is from the Anglo-Saxon papol, which meant something small and round, perhaps akin to the Latin word papula, a pustule.

Granule: Granules are rounded rock fragments larger than very coarse sand grains but smaller than pebbles. The granule is Rounded pieces are too small compared to Pebbles are still too large to be called sand grains. Granule word belongs to the Latin word granulum, diminutive of granum, grain, meaning a little grain, apellet. The grade term was chosen as best adapted for this grade of material.

Silt particle: Silt particles are solid sediment particles that are smaller than very fine sand grains, but larger than clay particles. Silt particles are typically between 0.002 and 0.05 millimeters in diameter. A variety of minerals, such as quartz, feldspar, and mica, make up their makeup.

Clay particle: Clay particles are smaller than silt particles. The term "clay" was chosen to describe these particles because it was thought to be the most likely to be accepted by everyone. Clay particles are individual pieces of sediment. In other words, clay particles are the smallest type of sediment particle. They are so small that they can only be seen under a microscope. Clay particles are made up of a variety of minerals, including aluminum, silicon, and oxygen.

Particle size analysis techniques

Direct measurement

While soil scientists generally focus on the fraction of soil that passes through a 2 mm aperture sieve, numerous soil classification systems categorize soils based on the amounts of particles larger than a certain size. Engineers tasked with relocating a large amount of soil may deem its thorough grading as crucial, while sieving can be used to size even large particles, direct on-site measurement is frequently more convenient. The largest particles can be sized with a tape measure, and those several tens of centimeters across can be measured using wooden or light alloy templates featuring holes of various shapes and sizes (Billi, 1984). (Caroni & Maraga, 1983) employed an adjustable caliper linked to a tape-punch, allowing for direct data transfer to a computer in the lab; today, an electronic caliper coupled with a data-logger could be used. (Hodgson, 1974) presented a technique for estimating the volume of particles larger than a certain sieve size using plastic spheres. (Laxton, 1980) utilized a photographic method to estimate the grading of boulder- and cobble-sized materials in the visible quarry working faces. (Buchter et al., 1994) discovered a strong correlation between the quantity of extremely coarse substances in a rendzina when measured by volume, standard particle size analysis, and thin section examination. When dealing with particles from about 10 cm to 1 mm in size, sieving is often the only feasible option due to their abundance, making other methods impractical. For particles between 1 mm and 20 mm, optical microscopy is the method of choice, while electron microscopy is reserved for particles under 1 mm. The benefit of using microscopy is its ability to consider particle shapes comprehensively. Accurate sampling and the measurement of numerous particles are essential for obtaining statistically sound results with microscopy (Afnor, 1988; Griffiths, 1967; Kiss & Pease, 1982).

Sieving

Sieves with openings from 125 mm down to 5 mm are offered in designs with either round or square holes, contingent on the aperture's size. Round-hole sieves categorize material by a single dimension, while square-hole sieves classify particles by two dimensions: both the space between two opposing sides and the diagonal connecting corners. The combined use of round and square-hole sieves can introduce significant errors in the creation of soil particle size distribution charts, leading many standards to now exclude round-hole sieves from use (Tanner & Jackson, 1948). Mechanical sieve shakers are often preferred over manual sieving due to their ability to deliver highly accurate results when operated with precision. The majority of errors are caused by worn or damaged screens, inconsistencies in sieve loading particularly from overloading, variations in shaking duration, improper alignment of sieves, lids, and receivers, as well as not maintaining the shaker level during operation (Head, 1992; Metz, 1985). As the aperture size decreases to around 30 mm or less, sieving becomes more challenging due to the rapid decline in the hole area relative to the total sieve area, as illustrated in Figure 1. Dry sieving is not advisable for such small apertures. If sieving is necessary, the air-jet method is faster and yields more consistent results than traditional sieving, Additionally, for finer materials prone to clumping, there are wet-sieving devices available (Loveland & Whalley, 2000). Sieve apertures often become clogged and are typically cleaned by brushing, but this process can harm the sieves, especially those with smaller openings, causing stretching or breakage of the mesh. Ultrasonic baths filled with propan-2-ol can be used for cleaning sieves, but the oscillation frequency must be carefully selected to prevent cavitation and weakening of the mesh. After each shaking, it’s advisable to inspect sieves and their accessories for damage. Bright, shiny fragments of brass or stainless steel, no matter how small, serve as a reliable indicator of sieve mesh failure.

Sedimentation

The most prevalent methods for determining particle size in soil science involve a combination of sieving and sedimentation. In this context, 'sedimentation’ refers to the settling of particles within a fluid due to gravity or centrifugal forces (Bascur, 2024; Olarte et al., 2023). The quantity of material above or below a specific size is assessed through various methods. These methods include extracting a portion of a suspension, drying the residue, and measuring its weight. Alternatively, one can analyze changes in the suspension's density or opacity or observe the sediment settling in a suitable container over a defined period. Regardless of the measurement method selected, all assume that suspended particles conform to the Stokes equation (as originally formulated by Stokes, 2007). (Odén, 1915) applied this equation to soil analysis. For spherical particles, the expression can be written as follows:

$$f(X) = \frac{1}{x^2 + x}$$

where (x) represents the relevant parameter.
In their work, (Gee & Bauder, 1986) explored the fundamental pipet methodology for routine soil analysis. A common concern is that this method becomes laborious when dealing with fractions smaller than 2 µm ESD. (Coventry & Fett, 1979) demonstrated how pipet analysis efficiency can be significantly enhanced by paying attention to time-saving details at each step of the process. In our Soil Survey laboratory, we have significantly reduced analysis time by creating a programmable automatic sampling device specifically designed for extracting silt-plus-clay and clay aliquots. In their work, (Elfaki et al., 2016) explored the fundamental pipet methodology for routine soil analysis. A common concern is that this method becomes laborious when dealing with fractions smaller than 2 µm ESD, how pipet analysis efficiency can be significantly enhanced by paying attention to time-saving details at each step of the process. In our Soil Survey laboratory, we have significantly reduced analysis time by creating a programmable automatic sampling device specifically designed for extracting silt-plus-clay and clay aliquots.

Centrifugation
Centrifugation extends the concept of sedimentation under gravity and provides a method for quantifying the quantities of particles with equivalent spherical diameters (ESD) less than 1 µm in suspension. These are particles whose settling behavior under gravity is significantly influenced by Brownian motion. In their work, (Tanner & Jackson, 1948) compiled detailed nomograms that describe the settling times of particles with various Stokes diameters during centrifugation. In sedimentation analysis, large volumes of suspension pose challenges for standard laboratory centrifuges. These centrifuges, with elongated cylindrical sedimentation vessels, lead to particle-wall collisions during centrifugation. To address this, modern centrifugal analyzers employ two designs based on the measurement zone radius and the inner surface radius (S) of the sedimenting column. In disk centrifuges, S/R tends to zero, resulting in radial sedimentation within a hollow rotating disk. Long-arm centrifuges, where S is large and S/R approaches 1, assume parallel sedimentation paths. Distinguishing between the two types involves observing suspension concentration changes after startup. The upper Stokes diameter determination, using water as a suspension medium, reaches about 7 mm ESD, extendable with more viscous liquids. The lower limit, influenced by Brownian motion, lies between 10 and 50 nm ESD (Loveland & Whalley, 2000). Centrifugal particle size analyzers operate in two modes. First, the sedimentation vessel can be filled with a homogeneous suspension at the beginning of analysis. Alternatively, the vessel is filled with a clear carrier liquid, and the suspension is floated onto it. These techniques are known as the homogeneous-start and line-start methods, respectively. It's worth noting that pipet sampling is not recommended for use with the line-start technique due to the typically low suspension concentration (Mitchell, 2000). In the context of pipet-sampling centrifuges, which utilize disk centrifuges with the homogeneous-start technique, the decrease in suspension concentration at the sampling point can be attributed to the sedimentation of different size fractions. Additionally, the diverging radial sedimentation paths of particles contribute to further dilution.
The centrifugal x-ray and photosedimentation methods continuously monitor the sedimenting suspension by measuring radiation transmission (either visible or x-ray) within a precisely defined measurement zone. A centrifugal disk x-ray particle size analyzer operates on principles quite similar to those of gravitational x-ray sedimentation. However, because a homogeneous start is employed with a disk centrifuge, data analysis must adhere to the theory outlined by (Svarovsky & Svarovska, 1975) to account for the radial dilution effect. The electrical sensing zone (ESZ) method is commonly referred to as the Coulter principle, named after its discoverer. Commercially available instruments, although not exclusively produced by the Beckman-Coulter Corporation, are generally known as Coulter counters. Coulter's discovery revolves around measuring the resistance between two electrodes submerged in an electrolyte. These electrodes are separated by an aperture with a known size and corresponding electrical characteristics. As particles pass through this aperture, the resistance changes proportionally to their volume. These resistance variations can be scaled and counted at a rapid rate, often reaching several thousand per second. In the Electrical Sensing Zone (ESZ) method, a precisely measured volume of suspension is drawn through an aperture using automatic manometer operation. As each particle passes through the aperture, the change in resistance between the electrodes generates a voltage pulse. This pulse is then scaled, amplified, and electronically assigned to a specific size class or channel. Depending on the aperture range, there can be up to 256 such channels. Leveraging microprocessors, the instrument output can be directly expressed as 'percent oversize' or as a cumulative distribution curve. However, it's crucial to recognize that the output represents a numerical size distribution, from which the total particle volume (with certain assumptions) is inferred based on the size class itself. The mathematical conversion to a weight basis was explored by (Batch, 1964).

Standard method for soil classification
Soil classification involves grouping soils based on specific characteristics, including particle size, mineralogy,

moisture content, and other relevant properties. Globally, various standard methods and systems are used for soil Classification (Table 1). These include the United States Department of Agriculture (USDA) methods, international soil science standards (ISSS), American Society for Testing and Materials (ASTM) guidelines, the Unified Soil Classification System (USCS), the International Soil Classification System for Naming Soils and Materials (ISCS), the AASHTO Soil Classification System, British Standard Classification (BS 5930), Australian Soil Classification (ASC), and the Canadian System of Soil Classification (CSSC).

Table 1 Different type Soil Classification systems

USDA		CSSC		ASTM		ISSS	
0.0002 mm	Clay	<0.0002 mm	Fine clay	0.0002 mm	Clay	0.0002 mm	Fine silt and clay
		0.0002 mm	Coarse clay				
0.002 mm	Silt	0.002 mm	Fine silt	0.002 mm	Silt	0.08 mm	Fine sand
0.04 mm	Very fine sand	0.005 mm	Medium silt				
0.1 mm	Fine sand	0.02 mm	Coarse silt	0.02 mm	Fine sand	0.4 mm	Medium sand
0.3 mm	Medium sand	0.05 mm	Very fine sand				
0.6 mm	Coarse sand	0.1 mm	Fine sand	0.25 mm	Coarse sand	2.0 mm	Coarse sand
1 mm	Vary coarse sand	0.3 mm	Medium sand	>0.2 mm	Gravel	5.0mm	Fine gravel
2 mm	Fine gravel	0.6 mm	Coarse sand				
10 mm	Coarse Gravel	1.0 mm	Vary coarse sand			20mm	Coarse Gravel
>80 mm	Cobbles	2.0 mm	Gravel			>80mm	Cobbles
		>80 mm	Cobbles				

United States Department of Agriculture (USDA)

The USDA soil classification system, also known as the USDA soil taxonomy, is a hierarchical system used to classify soils in the United States and several other countries. It was developed by the United States Department of Agriculture (USDA) and is widely used for soil characterization and mapping (Table 1). The system categorizes soils based on various soil properties, including soil horizons, composition, texture, color, structure, and other characteristics (Moreno-Maroto & Alonso-Azcárate, 2022).

Canada Soil Survey Committee (CSSC)

The CSSC categorizes soils into different classes based on their properties (Wang et al., 1978). The CSSC categorizes soils into different classes based on their properties, composition, and formation processes. These classifications are valuable for understanding the characteristics and behavior of soils, which is crucial for various fields, including agriculture, engineering, land use planning, and environmental applications studies (McKeague & Stobbe, 1978; Wang et al., 1978).

American Society for Testing & Materials (ASTM)
The ASTM soil classification system (Table 1), established by the American Society for Testing and Materials (ASTM) and now known as ASTM International, is widely used to classify soils for engineering and construction purposes in the United States. This system is primarily based on the particle size distribution and engineering properties of soils (Gee & Bauder, 1986).

International Society of Soil Science (ISSS)
The ISSS soil classification system allows for precise and systematic categorization of soils, facilitating communication and understanding among soil scientists, agronomists, environmentalists, and others involved in soil-related studies and applications (Yong & Warkentin, 1966). application is useful for geological engineers for soil surveys as well as agriculturists who are interested in soil types. The crop yield prediction application can be used directly by agro-industries to give valuable information to farmers who may be illiterate and not be able to use the software directly (Barman & Choudhury, 2020).

Model for estimation soil particle size distribution
The Particle size distribution in soil is frequently assumed to be approximately lognormal (Buchan, 1989; Campbell, 1985; Shirazi & Boersma, 1984), although soils with bimodal PSDs also occur (Walker & Chittleborough, 1986). (Buchan et al., 1993) compared five different lognormal models for experimental PSD data. Each of the five models accounted for >90% of the variance in the PSD of most of the soils examined, with the bimodal lognormal model proposed by (Shiozawa & Campbell, 1991) providing the best fit (Hwang et al., 1989). In this model soil particle distribution is the basic assumption of lognormality of soil particle is depending on basis of geometric mean size diameter and geometric standard deviation as mean size (Buchan, 1989). (Hwang et al., 2002) paper shows they use a parametric model for soil particle distribution. There are two basic approaches for representing the PSD parametric models of the full distribution. The first category for particle size distribution is the parametric model, which provides complete information about the soil particle distribution. For collecting complete information about soil particles, here are seven parametric models tested, including six that are unimodal and one that is bimodal. Jay is a one-parametric model (Esmaeelnejad et al., 2016), and a simple lognormal (SL) is a two-parametric model (Buchan, 1989). Brahman and Dev paper shows using the soil image using a liner kernel via a support vector machine classifier. This provides a variance of 91.37 percent accuracy of the soil sample and gets the best result.

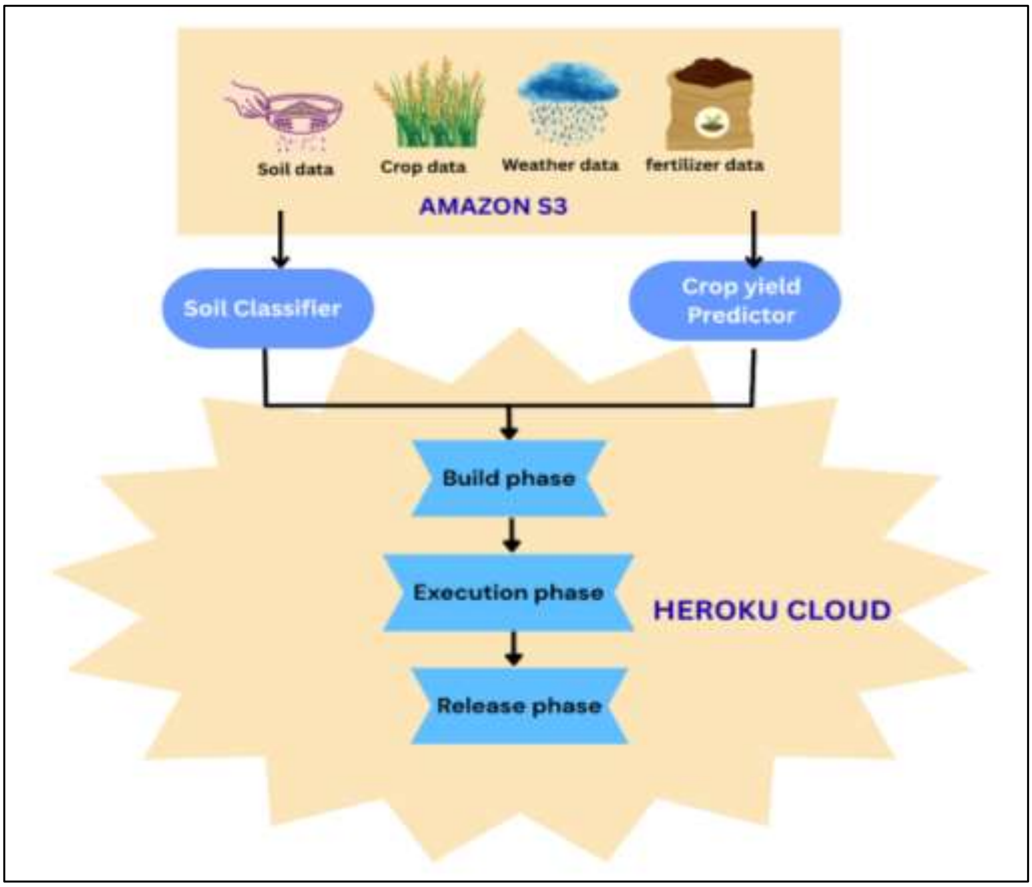

Figure. 1 Cloud-Based Agricultural Framework

Above fig.1 shows Cloud-Based Agricultural Framework (Fig. 1) (Shastry & Sanjay, 2019). In the first phase, Amazon S3 was used to store the soil data, crop data, weather data, and fertilizer data in the form of buckets. Soil samples containing data about pH, EC, OC, AvP, AvB, AvP, sand, silt, and clay were collected from NBSS (National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), 2023) and ICRISAT (Wani, Anantha, et al., 2011; Wani, Sahrawat, et al., 2011). And then proceed farther more. This result is close to the United States Department of Agriculture soil classification system; they provide the best results in sand and silty clay, but they need a little more accuracy for fine loamy sand and loamy sand (Barman & Choudhury, 2020). Shastry and Sanjay indicate the contribution of the cloud-based agricultural framework for soil classification based on hybrid support vector machines (M-SVM), and for wheat yield prediction, a customized artificial neural network (M-ANN) was developed. The paper suggested the development of mobile agricultural apps and functionalities for future soil classification, (Aditya Shastry & Sanjay, 2019) and here they build soil classification and crop yield prediction systems in a cloud environment for providing soil classification and crop yield prediction. They make an open-source platform called Heroku Cloud Platform for deploying cloud applications. And this work is done using MATLAB. The soil classification application is useful for geological engineers for soil surveys as well as agriculturists who are interested in soil types. The crop yield prediction application can be used directly by agro-industries to give valuable information to farmers who may be illiterate and not be able to use the software directly (Barman & Choudhury, 2020).

Kumar and Dutta demonstrated the mobile application developed for soil classification in this paper. The results show that the mobile app is useful for correctly classifying a large number of soils, making graphs, tables, and flowcharts manually, and solving erroneous soil classification errors. Further improvement in the mobile app development can be made for the missing input properties affecting the soil classification (Dutta et al., 2019). Augusto, Morais, and Souza worked together, and her paper highlighted that the prediction of soil texture could be made by using image analysis. The computer vision approach adopted for the recognition of soil textures based on soil images matched 100% of the classification predicted according to the standard method. The new way is low-cost, environment-friendly, non-destructive, and faster than the standard method. As a consequence, it opens up the possibility of employing a cell phone for image acquisition and instant recording of information on the field (de Oliveira Morais et al., 2019; Moreno-Maroto & Alonso-Azcárate, 2022). Analytical methodology for soil classification is based on the use of laser-induced breakdown spectroscopy (LIBS) and geometric techniques. Soil classification is based on the use of LIBS data and chemometrics methods. The methodology was validated in a case study involving three Brazilian soil types (Argissolo, Latossolo, and Nitossolo). Better discrimination of the soil types was attained by employing a subset of selected spectral variables for LDA, as compared to the use of full-spectrum SIMCA modeling. More specifically, the best results were obtained with SPA-LDA, which achieved an average classification rate of 90% in the validation set and 72% in cross-validation. Future works could investigate the combination of LIBS with other techniques, such as VIS-NIR spectroscopy, for the purpose of improving the classification outcome (Pontes et al., 2009).

Effect of particle size on soil physical and chemical properties

Impact on OC (Organic Carbon)

Larger surface area: Clay and silt particles, being finer, have a much larger surface area compared to sand. This allows them to adsorb and hold onto organic matter more effectively (Ahogle et al., 2022; Bi et al., 2023; Zhang et al., 2022). Protection from decomposition: Organic material trapped within these small pores is shielded from decomposers like microbes and fungi. This slows down the breakdown of organic matter, leading to a buildup of OC over time (Ahogle et al., 2022; Bi et al., 2023). Clay-OC association: Clay particles have a negative charge that attracts positively charged components of organic matter. This strong bond creates more stable forms of OC that decompose much slower (Ahogle et al., 2022; Bi et al., 2023).

Size and decomposition rate: Generally, OC associated with finer particles decomposes slower compared to OC associated with larger particles. This is because of the physical protection offered by the small pores and the strongest chemical bonds with clay (Ahogle et al., 2022; Zhang et al., 2022). Soils with a higher proportion of clay and silt particles tend to have a greater capacity to store organic carbon. These finer particles provide a larger surface area and physical protection for organic matter, promoting its accumulation and persistence in the soil. Land management practices like no-till farming and cover cropping can help increase organic matter content in soil, especially in the finer fractions (Ahogle et al., 2022). The relationship between particle size and OC can vary depending on factors like soil type, climate, and vegetation cover (Bi et al., 2023).

Impact on OM (Organic matter)

Clay-OM Bond: Clay particles have a negative charge that attracts positively charged components of organic matter. This strong bond creates more stable forms of organic matter that decompose at a much slower rate (Ahogle et al., 2022; Zhang et al., 2022).

Size Dictates Decomposition Rate: Generally, organic matter associated with finer particles decomposes slower compared to its counterpart associated with larger particles. This is primarily due to the physical protection offered by the small pores and the strongest chemical bonds with clay minerals (Bi et al., 2023; Zhang et al., 2022).

Impact of MC (Moisture Content) and WHC (Water Holding Capacity)

Soil particle size plays a significant role in both the moisture content and water holding capacity (WHC) of soil.

Soils with a higher proportion of clay and silt particles tend to have a higher moisture content and WHC. These finer particles provide more space for water to reside and create a stronger attraction to hold water molecules, allowing the soil to store more usable water for plants. Fine Particles, High Moisture Retention Clay and silt particles, due to their smaller size, have a much larger total pore space compared to sand. This allows them to hold more water molecules within these pores, leading to a higher overall moisture content. Stronger Hold Clay and silt particles, with their larger surface area, have more sites for water adsorption. This translates to a higher WHC, meaning the soil can retain more water against the pull of gravity (Mile & Mitkova, 2012; Zhang et al., 2022). While finer particles offer more total pore space, the size distribution of pores also matters. Large pores allow for faster drainage, while smaller pores hold water more tightly. A healthy soil has a mix of pore sizes for optimal water availability to plants. Organic matter also plays a role in WHC. It can act like a sponge, further increasing the capacity of the soil to hold water (Zhang et al., 2022).

Impact of agriculture on Soil Fertility

Conservation Agriculture CA aims to restore and maintain soil functions, including carbon cycling, nutrient dynamics, and structure maintenance. It shows commendable performance in crop yield, economic returns, greenhouse gas mitigation, biodiversity conservation, and overall soil health improvement. Traditional agricultural practices often compromise soil health, and soil degradation risks are common. CA emerges as an alternative to conventional management, providing essential ecosystem services through the soil for long-term sustainability (Caron et al., 2014). The impact of CA systems on soil health varies by location, influenced by soil and climatic conditions, the duration of CA operation, CA practices (cover crop types, crop rotation intensity), and the farmers' training and experience (Hermans et al., 2021a; Indoria et al., 2017; Kassam et al., 2014).

Soil Health Indicators

Soil health is crucial for sustainable agricultural management, but it's a complex concept that cannot be directly measured in the field or laboratory, but can be indirectly inferred through soil indicators (Mukherjee & Lal, 2014), and the indicators are measurable soil parameters that influence soil function and ecosystem (Cherubin et al., 2016). Soil health indicators can be physical, chemical, or biological (Table 2), but they are not always clearly defined due to multiple processes. No single indicator can cover all soil health processes or parameters, so a minimum dataset is necessary to represent total, data and minimize costs and efforts in soil health assessment. This dataset should include physical, chemical, and biological parameters to ensure accurate and comprehensive assessments (Lehmann et al., 2020).

Table 2 Type of indicators they influence soil fertility

Type of indicators	**Influence**
Biological	
N mineralization	Capacity of the soil to supply N for crop growth
Microbial biomass	Source of C and nutrients
Microbial activity	Availability of nutrients and biogeochemical cycles
Soil respiration	Indicator for biological activity and organic matter
Chemical	
Organic carbon	Important for soil structure and fertility, and WHC (water holding capacity)
Bio-available nutrient	Potential of nutrients to support plant development availability of nutrients
pH	Availability of nutrients
CEC	Soil's availability to supply plant nutrients
EC	Related to soil structure, infiltration and crop development
Potential pollutants	Potentially harmful for plant growth and soil health
Physical	
Penetration resistance	Related to infiltration capacity and erosion and runoff processes
Aggregation	Indicator of soil structure and erosion protection
Infiltration	Indicator for erosion and runoff
Depth to hardpan	Roots growth potential

Texture	Important for soil water and nutrient transfer and retention
Water-holding capacity	Sufficient moisture to support plant growth
*CEC (Cation exchange capacity), EC (Electrical conductivity). Compiled by authors from different sources (Cárceles Rodríguez et al., 2022; Cardoso et al., 2013; Hermans et al., 2021; Lehmann et al., 2020).	

Table 2 shows a dataset for soil health assessment consists of commonly used indicators that are easy to measure, measure with practical, rapid, and inexpensive methods, sensitive to manage variations, relevant to soil ecosystem functions, and informative for management (Doran & Zeiss, 2000; Rinot et al., 2019).

Conclusion

Soil particle size analysis emerges as a cornerstone technique for deciphering soil composition and behavior. This analysis reveals the fundamental building blocks of soil, influencing its characteristics and performance across diverse applications. Accurate and precise measurements are paramount, achievable through established techniques and the use of reliable reference materials. Soil particle size analysis goes beyond simply determining particle dimensions. By understanding how particle size distribution impacts various soil properties, this method empowers informed decision-making in numerous fields. In agriculture, knowledge of soil particle size is essential for optimizing crop yields and implementing sustainable land management practices. Similarly, engineers leverage this information to design robust and effective structures. Environmental scientists utilize it to assess soil health and predict its impact on broader ecological processes. In conclusion, soil particle size analysis serves as a powerful tool, unlocking a deeper understanding of soils and empowering informed practices in agriculture, engineering, environmental science, and beyond.

Beyond Measurement: Unveiling Soil-Property Relationships Soil particle size analysis goes beyond mere particle dimension measurement. It delves into the impact of particle size distribution on various soil properties, including water holding capacity, nutrient retention, and aeration. These relationships provide invaluable knowledge for scientists and practitioners in diverse fields such as agriculture, engineering, and environmental science, empowering informed decision-making for sustainable soil management and environmental protection.

Acknowledgement

we would like to express our sincere thanks to the Department of Life Sciences, Patan for providing the resources, facilities, guidance, and continuous support that enabled the successful completion of this research.

Competing Interests

The authors declare there are no competing interests.

Founding Declaration

The authors declare there was no Funding.

Author Contributions

Ganesh Parmar conceived and designed the study and prepared the original manuscript. Radha Rajput contributed to manuscript editing and revision. Pravinkumar Rajgadhi performed the data analysis. Shreyas Bhatt contributed to data interpretation and critically revised the manuscript. Gaurang Chudasama contributed to manuscript revision and coordinated the finalization of the manuscript. All authors read and approved the final version of the manuscript.

References

1. **Aditya Shastry, K., & Sanjay, H. A.** (2019). Cloud-Based Agricultural Framework for Soil Classification and Crop Yield Prediction as a Service. Emerging Research in Computing, Information, Communication and Applications: ERCICA 2018, Volume 1, 685–696.
2. **Afnor, N. N. F. X**. (1988). NFX 50-120-ISO 8402. AFNOR, Paris.
3. **Ahogle, A. M. A., Alladassi, F. K., Akplo, T. M., Azontonde, H. A., & Houngnandan, P.** (2022). Assessing Soil Organic Carbon Stocks and Particle-Size Fractions across Cropping Systems in the Kiti Sub-Watershed in Central Benin. C, 8(4), 67.
4. **Arriaga, F., Lowery, B., & Mays, M.** (2006). A fast method for determining soil particle size distribution using a laser instrument. Soil Science - SOIL SCI, 171, 663–674. https://doi.org/10.1097/01.ss.0000228056.92839.88
5. **Atterberg, A.** (1916). The classification of humus-free and low-humus mineral soils of Sweden according to their consistency characteristics. Publisher for Technical Literature.
6. **Barman, U., & Choudhury, R. D.** (2020). Soil texture classification using multi class support vector machine. Information Processing in Agriculture, 7(2), 318–332.
7. **Barth, H. G., & Sun, S. T.** (1989). Particle size analysis. Analytical Chemistry, 61(12), 143–152.
8. **Bascur, O. A.** (2024). The Engineering Science of Mineral Processing: A Fundamental and Practical Approach. CRC Press.
9. **Batch, B. A.** (1964). The application of an electronic particle counter to size analysis of pulverized coal and fly-ash. J. Inst. Fuel, 37, 455.
10. **Billi, P**. (1984). Quick field measurement of gravel particle size. Journal of Sedimentary Research, 54(2).

11. Bi, X., Chu, H., Fu, M., Xu, D., Zhao, W., **Zhong, Y., Wang, M., Li, K., & Zhang, Y.** (2023). Distribution characteristics of organic carbon (nitrogen) content, cation exchange capacity, and specific surface area in different soil particle sizes. Scientific Reports, 13(1), 12242.
12. **Buchan, G. D.** (1989). Applicability of the simple lognormal model to particle-size distribution in soils. Soil Science, 147(3), 155–161.
13. **Buchan, G. D., Grewal, K. S., & Robson, A. B.** (1993). Improved models of particle-size distribution: An illustration of model comparison techniques. Soil Science Society of America Journal, 57(4), 901–908.
14. **Buchter, B., Hinz, C., & Flühler, H.** (1994). Sample size for determination of coarse fragment content in a stony soil. Geoderma, 63(3–4), 265–275.
15. **Campbell, G. S.** (1985). Soil physics with BASIC: transport models for soil-plant systems. Elsevier.
16. **Cárceles Rodríguez, B., Durán-Zuazo, V. H., Soriano Rodríguez, M., García-Tejero, I. F., Gálvez Ruiz, B., & Cuadros Tavira, S.** (2022). Conservation agriculture as a sustainable system for soil health: A review. Soil Systems, 6(4), 87.
17. **Cardoso, E. J. B. N., Vasconcellos, R. L. F., Bini, D., Miyauchi, M. Y. H., Santos, C. A. dos, Alves, P. R. L., Paula, A. M. de, Nakatani, A. S., Pereira, J. de M., & Nogueira, M. A.** (2013). Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Scientia Agricola, 70, 274–289.
18. **Caroni, E., & Maraga, F.** (1983). Granulometric measurements in natural riverbeds using a recording caliper. Applied Geology and Hydrogeology, 18, 19–31.
19. **Caron, P., Biénabe, E., & Hainzelin, E.** (2014). Making transition towards ecological intensification of agriculture a reality: the gaps in and the role of scientific knowledge. Current Opinion in Environmental Sustainability, 8, 44–52. https://doi.org/10.1016/j.cosust.2014.08.004
20. **Cherubin, M. R., Karlen, D. L., Cerri, C. E. P., Franco, A. L. C., Tormena, C. A., Davies, C. A., & Cerri, C.** (2016). Soil quality indexing strategies for evaluating sugarcane expansion in Brazil. PloS One, 11(3), e0150860.
21. **Coventry, R. J., & Fett, D. E. R.** (1979). A pipette and sieve method of particle-size analysis and some observations on its efficacy.
22. **de Oliveira Morais, P. A., de Souza, D. M., de Melo Carvalho, M. T., Madari, B. E., & de Oliveira, A. E.** (2019). Predicting soil texture using image analysis. Microchemical Journal, 146, 455–463.
23. **Doran, J. W., & Zeiss, M. R.** (2000). Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology, 15(1), 3–11.
24. **Dutta, R. K., Dutta, K., Kumar, R., & Chaudhary, S.** (2019). Development of mobile app for the soil classification. I-Manager's Journal on Mobile Applications and Technologies, 6(1), 34.
25. **Elfaki, J., Siddig, M., & Ali, M.** (2016). Hydrometer method against Pipette method for Estimating Soil particle size distribution in Some Soil Types Selected from Central Sudan. International Journal of Engineering Research, 2, 25–41.
26. **Esmaeelnejad, L., Siavashi, F., Seyedmohammadi, J., & Shabanpour, M.** (2016). The best mathematical models describing particle size distribution of soils. Modeling Earth Systems and Environment, 2, 1–11.
27. **Gee, G. W., & Bauder, J. W.** (1986). Particle-size analysis. Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 5, 383–411.
28. **Geology, U. of Chicago. D.** (1922). The Journal of Geology (Issue v. 30). University of Chicago Press. https://books.google.co.in/books?id=KHfzAAAAMAAJ
29. **Griffiths, J. C.** (1967). Scientific method in analysis of sediments.
30. **Head, K. H.** (1992). Manual of soil laboratory testing. Volume 1. Soil classification and compaction tests.
31. **Hermans, T. D. G., Dougill, A. J., Whitfield, S., Peacock, C. L., Eze, S., & Thierfelder, C.** (2021). Combining local knowledge and soil science for integrated soil health assessments in conservation agriculture systems. Journal of Environmental Management, 286, 112192.
32. **Hodgson, J. M.** (1974). Soil survey field handbook.
33. **Hwang, S. Il, Lee, K. P., Lee, D. S., & Powers, S. E.** (2002). Models for estimating soil particle-size distributions. Soil Science Society of America Journal, 66(4), 1143–1150.
34. **Hwang, J.-J., Chow, Y.-C., Anger, F. D., & Lee, C.-Y.** (1989). Scheduling precedence graphs in systems with interprocessor communication times. Siam Journal on Computing, 18(2), 244–257.
35. **Indoria, A. K., Rao, C. S., Sharma, K. L., & Reddy, K. S.** (2017). Conservation agriculture–a panacea to improve soil physical health. Current Science, 52–61.
36. **Kassam, A., Derpsch, R., & Friedrich, T.** (2014). Global achievements in soil and water conservation: The case of Conservation Agriculture. International Soil and Water Conservation Research, 2(1), 5–13.
37. **Kiss, K., & Pease, R. N.** (1982). Quantitative analysis of particle sizes: Estimation of the most efficient sampling scheme. Journal of Microscopy, 126(2), 173–178.
38. **Laxton, J. L.** (1980). A method for estimating the grading of boulder and cobble grade material.
39. **Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C**. (2020). The concept and future prospects of soil health. Nature Reviews Earth & Environment, 1(10), 544–553.
40. **Loveland, P. J., & Whalley, W. R.** (2000). Particle size analysis. In Soil and Environmental analysis (pp. 293–326). CRC Press.
41. **McKeague, J. A., & Stobbe, P. C**. (1978). History of soil survey in Canada 1914-1975.
42. **Metz, R.** (1985). The importance of maintaining horizontal sieve screens when using a Ro-Tap. Sedimentology, 32(4), 613–614.

43. **Mile, M., & Mitkova, T.** (2012). Soil Moisture Retention Changes in Terms of Mineralogical Composition of Clays Phase. In M. Valaškova & G. S. Martynkova (Eds.), Clay Minerals in Nature (p. Ch. 6). IntechOpen. https://doi.org/10.5772/48098
44. **Mitchell, J. P.** (2000). Particle standards: their development and application. KONA Powder and Particle Journal, 18, 41–59.
45. **Moreno-Maroto, J. M., & Alonso-Azcárate, J.** (2022). Evaluation of the USDA soil texture triangle through Atterberg limits and an alternative classification system. Applied Clay Science, 229, 106689.
46. **Mukherjee, A., & Lal, R.** (2014). Comparison of soil quality index using three methods. PloS One, 9(8), e105981.
47. National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). (2023, June 5). Nbsslup.in. Https://Nbsslup.In/.
48. **Odén, S.** (1915). Eine neue Methode zur mechanischen Bodenanalyse. Verlag für Fachliteratur.
49. **Olarte, M. C., Ruge, J. C., & Rodriguez-Rebolledo, J. F.** (2023). Synthesized Approach for Evaluating the Integral Suspension Pressure (ISP) Method and the Hydrometer in the Determination of Particle Size Distribution. Sustainability, 15(8), **6847.**
50. **Pontes, M. J. C., Cortez, J., Galvão, R. K. H., Pasquini, C., Araújo, M. C. U., Coelho, R. M., Chiba, M. K., de Abreu, M. F., & Madari, B. E.** (2009). Classification of Brazilian soils by using LIBS and variable selection in the wavelet domain. Analytica Chimica Acta, 642(1–2), 12–18.
51. **Rinot, O., Levy, G. J., Steinberger, Y., Svoray, T., & Eshel, G.** (2019). Soil health assessment: A critical review of current methodologies and a proposed new approach. Science of the Total Environment, 648, 1484–1491.
52. **Shastry, K. A., & Sanjay, H. A.** (2019). Cloud-based agricultural framework for soil classification and crop yield prediction as a service. Emerging Research in Computing, Information, Communication and Applications, 685–696.
53. **Shiozawa, S., & Campbell, G. S.** (1991). On the calculation of mean particle diameter and standard deviation from sand, silt, and clay fractions. Soil Science, 152(6), 427–431.
54. **Shirazi, M. A., & Boersma, L**. (1984). A unifying quantitative analysis of soil texture. Soil Science Society of America Journal, 48(1), 142–147.
55. **Stokes, G. G.** (2007). On the theories of the internal friction of fluids in motion, and of the equilibrium and motion of elastic solids.
56. **Svarovsky, L., & Svarovska, J.** (1975). Centrifugal sedimentation data analysis by analogue deconvolution. Journal of Physics D: Applied Physics, 8(2), 181.
57. **Tanner, C. B., & Jackson, M. L**. (1948). Nomographs of sedimentation times for soil particles under gravity or centrifugal acceleration. Soil Science Society of America Journal, 12(C), 60–65.
58. **Walker, P. H., & Chittleborough, D. J.** (1986). Development of particle-size distributions in some Alfisols of southeastern Australia. Soil Science Society of America Journal, 50(2), 394–400.
59. **Wang, C., Mckeague, J. A., & Beke, G. J.** (1978). Site characteristics, morphology and physical properties of selected ortstein soils from the Maritime Provinces. Canadian Journal of Soil Science, 58(3), 405–420.
60. **Wani, S. P., Anantha, K. H., Sreedevi, T. K., Sudi, R., Singh, S. N., & D'Souza, M.** (2011). Assessing the environmental benefits of watershed development: evidence from the Indian semi-arid tropics. Journal of Sustainable Watershed Science and Management, 1(1), 10–20.
61. **Wani, S. P., Sahrawat, K. L., Sarvesh, K. V, Baburao, M., & Krishnappa, K.** (2011). Soil fertility atlas for Karnataka, India. International Crops Research Institute for the Semi-Arid Tropics.
62. **Wentworth, C. K.** (1922). A scale of grade and class terms for clastic sediments. The Journal of Geology, 30(5), 377–392.
63. **Wentworth, C. K.** (1922). A Scale of Grade and Class Terms for Clastic Sediments. The Journal of Geology, 30(5), 377–392. http://www.jstor.org/stable/30063207
64. **Yingst, R. A., Cropper, K., Gupta, S., Kah, L. C., Williams, R. M. E., Blank, J., Calef, F., Hamilton, V. E., Lewis, K., Shechet, J., McBride, M., Bridges, N., Frias, J. M., & Newsom, H**. (2016). Characteristics of pebble and cobble-sized clasts along the Curiosity rover traverse from sol 100 to 750: Terrain types, potential sources, and transport mechanisms. Icarus, 280, 72–92. https://doi.org/https://doi.org/10.1016/j.icarus.2016.03.001
65. **Yong, R. N., & Warkentin, B. P.** (1966). Introduction to Soil Behavior. Macmillan. https://books.google.co.in/books?id=B9lRAAAAMAAJ
66. **Zhang, J., Li, G., Ding, S., Tian, H., Ren, X., Liu, M., & Zheng, Y.** (2022). Distribution characteristics of soil particles and their relationships with soil organic carbon components in the alluvial/sedimentary zone in the lower reaches of the yellow river. Frontiers in Environmental Science, 10, 849565.