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Soil Forensics: Systematic Approaches For Soil Analysis In Criminal Investigations

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Abstract:
Forensic soil analysis employs various disciplines, including soil science, to bolster criminal investigations. Soil is the most important physical evidence in all these relevant situations. Like fingerprints, every kind of soil contains unique features that act as distinguishing markers so that it can be allowed as evidence in a court of law. Soil science is the study of soil, and forensic soil science applies soil science to legal inquiries concerning any crime scene. It is therefore possible to identify the offender by tracking the soil sample's original origin. It is possible to link criminals to a particular type of dirt discovered at the crime scene. The current study's goal is to look at the unique characteristics of distinct soil types. These characteristics of the soil, in addition to other evidence discovered at a crime scene, might be useful in forensic investigations. Through case studies, we are examining the development of soil analysis in forensic science in this work. We have briefly reviewed the methods used in forensic science to analyse soil samples.

Keywords: *Forensic Analysis, Soil Analysis, Crime Evidence, Criminal Investigation, Soil Forensic.*

1. Introduction:

In criminal investigations, soil forensics is essential since it offers important details about a crime scene. It entails a methodical approach to soil sample analysis to find evidence that could be missed or obscured from view. Experts in soil forensics utilise a range of techniques to analyse the physical, chemical, and biological properties of soil to look for indications of criminal activity. Many areas of science, including pedology, soil mineralogy, soil morphology, soil mapping, soil microbiology, soil chemistry, isotope geochemistry, geographical information systems (GIS), and statistical analysis, are included in the theoretical techniques used in soil forensics to answer forensic legal questions, problems or hypotheses (Fitzpatrick 2009). Soil analysis is particularly crucial in criminal investigations where there is a chance that soil evidence can connect suspects, victims, or crime scenes. The majority of soil incidents include tyre marks or footprints that have been embedded in the ground. Soil forensics is a branch of soil science that applies soil science to the in-depth investigation of soil. Every type of soil contains unique qualities that operate as identifying markers to enable it to be admitted as evidence in a court of law, much like fingerprints. This suggests that tracing the origin of the soil sample will help identify the culprit. Soil differs in colour and texture due to its complexity, which includes a variety of naturally occurring rocks, minerals, plant fragments, and man-made components. Given this complexity, several approaches have been developed for forensic science purposes, such as mineral identification (Hirokawa et al., 2016), elemental analysis (Uitdehaag et al., 2016), and colour comparison (Guedes et al., 2009). Additionally, reports concerning the analysis of pollen grains, spores, organic materials (Chauhan et al., 2018), plant fragments (Chen et al., 2010), and pollen grains have been published (Morgan et al., 2014).

2. **Literature review**: Using soil as the most significant physical evidence, forensic soil analysis uses soil sciences and other fields to support criminal investigations. Similar to fingerprints, the distinct characteristics of soils serve as markers for identification. They can be traced back to the soil sample's original location, enabling the offender to be identified in court. The author (**Fitzpatrick, 2004)** has given background information on the importance of comprehending "earth materials," from the landscape scale to the crime scene to microscopic scale investigations, to assist law enforcement agencies in the investigation of serious, organised, criminal, and environmental crimes as well as acts of terrorism. applications of earth materials in forensic science and clearly shows forensic geology and soil science as thriving subdisciplines of geology and soil science that deserve the widest exposure in corporate and academic geosciences, law enforcement, and the police. **Marumo (2003)** conducted a comprehensive observation of the various hues of soil that were identified as beneficial for screening. The examination of soil components, which include closely related substances like plant fragments, pollen, spores, and diatoms, is advised by the author **(Sarawong et al., 2016).** Parent materials, temperature, moisture content, vegetation, time, and chemical reactions including oxidation, reduction, and solution, as well as human activity, all play a role in the development of soil. Soil colour is a powerful indicator of a soil's development history as a result of this intricate soil formation process **(Pitts & Clarke, 2020)**. The diversity of soil samples, which emerges from various soil processes on parent rock depending on ecological parameters like terrain and climate, makes forensic soil research a complex task **(Babu et al., 2023; Guedes et al., 2009)**. Investigators can distinguish between soils that may appear to be identical because of this variety. Soil sample collection is usually the first step in forensic soil testing (**Marumo, 2003**). Depending on the specifics of the criminal case and its surrounding circumstances, various analytical methodologies have varying degrees of relevance and resolution**(Chen et al., 2010)**. Every approach has advantages and disadvantages. As more techniques become quantitative and digital, using them together as digital profiles will make it easier to define soils of various sizes and with greater accuracy **(Hachem et al., 2020)**. The development and usage of databases will aid in the refinement and narrowing of the likely origin of a questioned sample in police intelligence, as well as provide increasingly robust sample comparisons for evidence. The new methodologies should be tested using the current soil databases.

According to **Sangwan et al. (2020)**, analytical soil science is essential to environmental and criminal forensics. It is a rapidly expanding discipline of forensic science. In criminal investigations, soil is frequently employed as tangible evidence due to the increased awareness on a global scale of the importance of soil data for intelligence operations and court evidence. Additionally useful in locating and stopping environmental crimes is environmental forensics. To find crime scenes and control sites, forensic geologists employ particle size distribution studies and colour analysis. ATR-FTIR, pyGC-MS, and NMR methods can all be used to estimate organic matter. The inorganic components of soil are also essential for examination; soil samples can be readily compared and distinguished based on their elemental makeup using combination techniques such as SEM-EDX and ICP-OES **(Chauhan et al., 2018)**.

According to **Dawson and Hillier (2010),** soils are evidence that links a subject or item to a certain place. Soil is valuable since it's everywhere and can be transferred to other materials or humans. Because soil is complex, studying its inorganic and organic components can yield complementary and independent information on the soil's geological origin, dominant vegetation, management, and environment. An overview of various techniques for characterising soil is provided in this study, including chemical analysis, mineralogy, and palynology, as well as novel methods like DNA profiling and profiling of other digital data like that from infrared spectroscopy, X-ray powder diffraction, and organic marker analysis **(Hirokawa et al., 2016)**. In order to do preliminary screens of soil samples for use in forensic science intelligence-led investigations and court presentations, the author **(Woods et al., 2014)** proposes that trace evidence laboratories make use of their current technologies. Geological experts and trace evidence laboratories must collaborate in order to increase the use of soil tests. By regularly examining soil samples in trace forensic science labs, trace evidence scientists can support forensic soil specimen investigations. Colour measurement and material differentiation can be accomplished with methods such as MSP and ATR-FTIR. Forensic-sized soil sample objective colour measurement is made simple by employing MSP spectra and CIE L*a*b* chromaticity coordinates. By analysing both organic and inorganic components of a soil specimen, ATR-FTIR may produce an extremely discriminating infrared spectrum. This permits traces of evidence.

The availability and fundamentals of soil identification for forensic trace evidence based on LIBS and FTIR-ATR spectra by PCA were examined by **Xu et al. (2020).** The findings indicated that FTIR-ATR and LIBS spectra might be used to identify between five different types of soil. Based on LIBS and FTIR-ATR spectra, the differences in elemental, mineral, and organic matter content among the various soil types serve as critical indications for soil identification. The two case studies' application of FTIR-ATR and LIBS spectra to soil analysis for forensic investigations shows the considerable potential for using FTIR-ATR and LIBS spectra in forensic science.

This paper offers a thorough examination of soil analysis and the various techniques employed in the process. The analysis of soil analysis, which supports criminal investigations, is the goal of this endeavour. A systematic strategy uses several instrumental soil analysis techniques. Finally, examine the case studies to investigate the concrete strategy.

3. **Soil Analysis**: A useful forensic technique for determining the suspect's movements and location is soil analysis. In criminal investigations, a variety of techniques have been employed to compare soil and establish provenance. When using soil analysis for forensic investigations around the middle of the 1800s, the main methods of acquiring evidence were morphological and light optical techniques (Fitzpatrick, 2004). Even if these are still in use today, more advanced techniques have been used.

Properties of soil:

1. **Colour**: Soil varies in hue because of the materials it contains. The techniques concentrate on specific soil components, like the organic or clay fractions. Figure 1 shows the soil's texture class

based on the proportion of clay, silt, and sand. The method provides enough discrimination to be included in a typical soil comparison methodology (Pitts & Clarke, 2020).

a. The black colour of the soil is due to organic matter.
b. Iron compound impurities make it red or brown.
c. The white or light colour of the soil is due to the silica mixture.
d. The bluish and greenish colour of soil is due to oxidation and reduction of iron oxide.
e. Its mottled hue is caused by the combination of iron and magnesium compounds in both wet and dry environments.

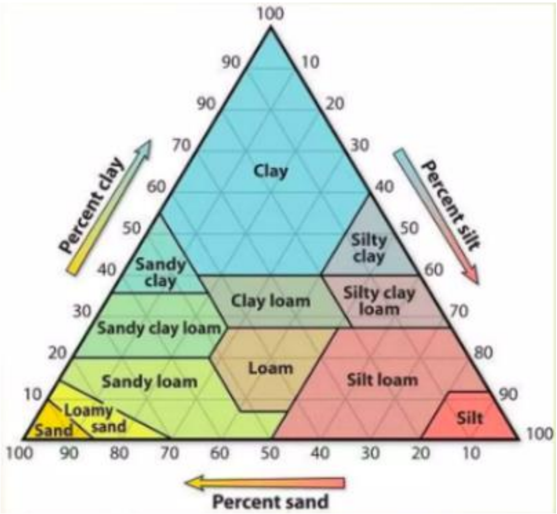


Figure 1: Topographical triangle illustrating a soil's texture class based on the proportion of clay, silt, and sand (Hachem et al., 2020).

2. Texture: Soil texture is categorised into three types: silt,
sand and clay are shown in figure 2 (Babu et al., 2023).

Clay Soil: Phyllosilicates, metal oxides, and organic materials with water deposition make up its composition. It has a high specific area and a smooth feel. Because of its capacity to retain water, its infiltration rate is lower. Clay soil has particles with a diameter of less than 0.002 mm.

Sand Soil: The majority of its constituents are quartz, along with felspar, mica, silica, zircon, and other heavy minerals. The range of its particle size is 0.063 mm to 2 mm. Depending on the intricacy of the mixture, it could have a smooth or rough texture. Its low water-holding capacity accounts for its high infiltration rate.

Silt Soil: All it is is quartz and feldspar-based stone dust, commonly referred to as "rock flour." Between 0.002 and 0.063 mm is the range of its particle size. It is covered in clay and has a smooth surface. This kind of soil has an adequate amount of moisture and fertility.

Figure 2: Different forms of soil.

3. Density: Measuring density is another physical characteristic that is employed. This can be accomplished in terms of the material or particle density; the precise type of soil being measured will determine how this measurement is made.

4. Particle size distributions: One of the most distinguishing physical characteristics is particle size, which is determined by particle size frequency distributions. This comprises the material's weight, weight percentage, volume, and particle count. Depending on the sample, a variety of techniques can be used, such as laser diffraction, dry or wet sieving, computer programme analysis, and many more.

5. pH: The level of hydrogen ion dissociation is calculated to get the pH, which is a measure of the hydrogen activity present. In terms of pH, it might be associated with acidic, basic, or neutral (Babu et al., 2023). Even while pH can also be used to identify other things like elemental composition, toxicity, and the amount of vital nutrients present, it may also be used to estimate the amount of lime necessary and indicate the existence of several elements like P, Zn, B, Cu, Fe, etc. The quality of field-use portable pH monitors has greatly increased recently. Many electrode-related failures plagued portable gadgets decades ago. These days, pH metres offer better overall unit safety in addition to lowering device costs thanks to microcircuitry and plastic. Additional research is trying to develop a method that uses plant cells and micro procedures to create a device that measures the pH of the microsite in different soil systems. This would also be capable of interpreting the various pH values found in the soil matrix

4. Soil Analysis Aids in Criminal Investigations:

1. Evidence Collection:

To fully depict the area, meticulous soil sample collection from various crime scene locations is necessary. Soil samples are taken from a variety of sites at crime scenes, including under the victim's body, tyre tracks, footprints, and potential walking or crawling regions for the suspect. Precise documentation of the sampling locations, depth, and time is necessary for accurate interpretation. Soil samples may be inspected for evidentiary remnants such as hairs, fibres, glass shards, or paint chips. These bits of evidence

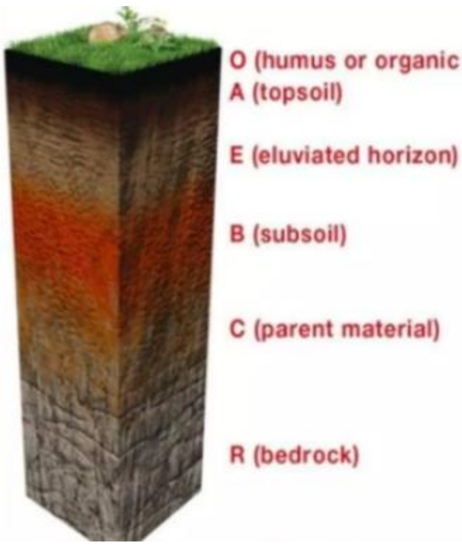


Figure 3: Different layers of soil composition.

could be compared to samples from the suspect's clothing, vehicle, or other relevant sources to make links (Nur et al., 2023).

2. **Soil Profiling**:
Soil samples from the crime scene are matched with soil samples from other places as part of the soil profiling process to determine if any matches can be found. The soil profile is reduced to a vertical cross-section of the soil's layers. These layers' quality and stability are understood by dividing them into numerous horizons. The humus, or organic, topsoil, eluviated horizon, subsoil, parent material, and bedrock are some of these horizons visualise in figure 3. It aids in determining if the victim or offender was present at a particular place.
3. **Footwear Analysis**:
Soil samples can be used to investigate footwear imprints. The presence of unique soil particles in the shoe treads can help identify the type of footwear the perpetrator was wearing. Lowering the number of suspects might facilitate the discovery of potential matches.
4. **DNA Analysis**:
Soil samples can provide DNA evidence, especially when there is little biological material available. Soil particles can collect and analyse DNA from blood, saliva, or skin cells to identify the perpetrator (Saadat et al., 2022).
5. **Geochemistry**:
Geochemistry examines the chemical composition of soil samples to determine their origin and potential sources. According to Pringle et al. (2012), this information can be utilised to track the suspect or victim around and ascertain their connection to specific locations.
6. **Pollen and Plant Analysis**:
Details regarding the vegetation that was present at the murder scene can be gleaned from pollen grains and plant fragments discovered in soil samples. This can assist in determining the year in whichon or time of year the crime occurred.
7. Forensic Entomology:Soil analysis has applications in forensic entomology, the study of insects and their usage in criminal investigations. The presence of specific bug species or their larvae in the soil can provide information about the post-mortem period and the surrounding environment at the crime scene.
8. Buried Remains:To locate buried remains, soil analysis might be rather crucial. Variations in the soil's composition, texture, or colour could indicate disturbed soil, which could be a potential burial site.
Forensic science, criminal investigation, and soil science expertise are required for the complex and specialist field of soil analysis. Soil analysis is a useful tool for law enforcement agencies to help them investigate crimes, identify the guilty, and bring victims' rights to justice.
5. Systematic Approach: The meticulous approach involves several analyses. Soil samples that are utilised as evidence are put through several methodical analyses. Forensic soil analysis typically uses several tests (Hachem et al., 2020). These are a few, enumerated below:
1. **Microscopic Analysis**:
Optical microscopy is the visual examination of soil particle form, colour, and texture using a light microscope. The method known as scanning electron microscopy, or SEM, allows for high-resolution imaging of soil samples so that the mineral content and surface features may be seen. According to Xu et al. (2020), SEM showed effective element detection but was unable to discriminate between ionic and non-ionic components. Soil samples are examined in polarised light using a technique called Polarised Light Microscopy (PLM) to look for refringent minerals and organic components.
2. Chemical Analysis:
Compounds and pollutants in soil samples are found using spectroscopic methods such as Raman spectroscopy and Fourier-transform infrared spectroscopy (FTIR). FTIR finds it difficult to distinguish

between samples from comparable surroundings, though. Chemicals, pesticides, and medications found in soil can be identified using chromatographic techniques such as liquid chromatography-mass spectrometry (LC-MS) and gas chromatography-mass spectrometry (GC-MS). These techniques are straightforward, non-destructive, and necessitate little sample preparation. For elemental analysis, X-ray fluorescence (XRF) is employed.

3. Mineralogical Analysis:

- A method for identifying and quantifying mineral phases in soil sample materials is called X-ray diffraction (XRD). It offers advantages including small sample sizes, non-destructive procedures, convenience of use, and crystal property determination. It examines crystal forms in elemental compositions and soil. Its shortcomings include its inability to distinguish between amorphous compounds and identify species in small concentrations. The mineral content and elemental concentrations of soil can be determined using X-ray fluorescence (XRF), and the organic matter can be analysed using nuclear magnetic resonance (NMR) to differentiate between alkyl, aromatic, carbonyl, and carboxylic carbons.

4. Isotopic Analysis:

Finding stable isotope ratios (such as those of carbon, nitrogen, and oxygen) in soil samples allows researchers to infer information about the soil's geographical origin, environmental background, and human influence.

5. Physical Property Analysis:

The assessment of the distribution of soil particle sizes—such as sand, silt, and clay—through the application of sedimentation or sieving techniques is known as texture analysis. In order to characterise the composition and texture of the soil, measurements of bulk density, particle density, and porosity must be accomplished.

6. Biological Analysis:

The process of identifying plant species, microbial communities, and human or animal DNA from soil samples is known as DNA extraction and analysis. Pollen grains, spores, or other minute plant remnants found in soil samples are examined by palynologists to determine vegetation and environmental conditions.

7. Geographic Information Systems (GIS):

To find patterns, correlations, and spatial relationships, mapping and spatial analysis of crime scenes, soil sample sites, and other pertinent spatial data are performed.

8. Comparative Analysis:

Comparative microscopy process is used for comparing soil samples side by side under a microscope to find patterns or distinctions in the organic composition, mineralogy, or particle shape. To quantify and contrast soil properties across several samples or locations using multivariate statistical techniques (e.g., discriminant analysis, cluster analysis).

6. Case Study:

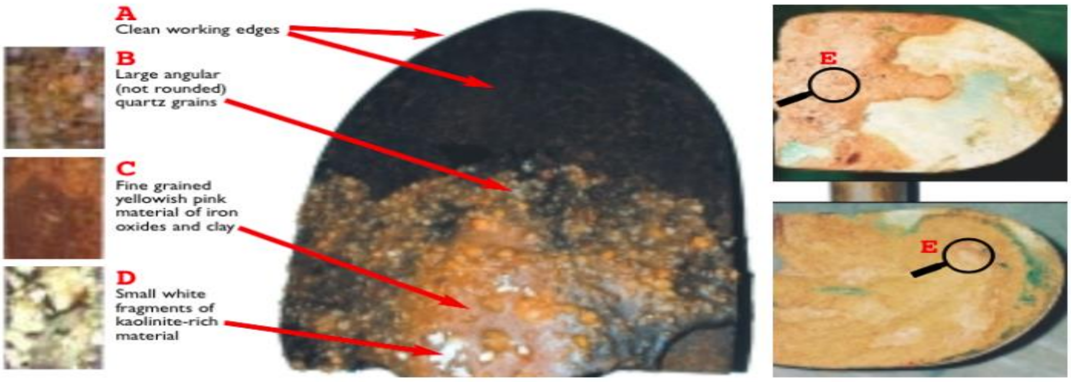
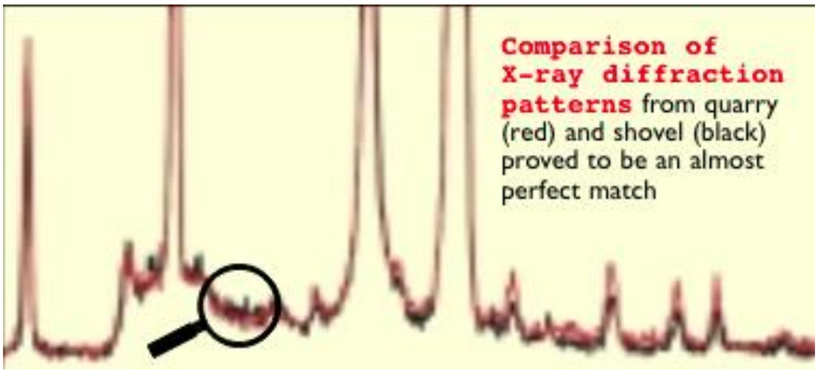


Figure 4: Evidence collected from the crime scene.

Case Study 1: Double Murder Case: A mother, her son, and an Australian woman were reported missing in 2000. The following day, a mother's automobile was found abandoned on Yorke Peninsula. Among the items discovered are dirty and blood-stained shovels. Moonta was captured by the suspect, who chose not to provide a statement. Nowadays, searching the whole area for dead bodies—from Oakbank to Moonta—has become challenging. To find any hints as to where the bodies might have been, soil forensics studied the soil material on both the front and rear of the shovel.

Figure 5: X-ray diffraction pattern.



Initial examination result refer to figure 4:

➔ The smeared structure and smooth working edges (A) imply use in damp soil.

➔ Cement-filled dirt stuck to the shovel blade's back, indicating wetness. The way the dirt appeared on the front of the shovel blade suggested that it had been wet and messy.

➔ The shovel had been used to level the soil, as evidenced by the compacted soil inside the handle housing on the rear. The large, angular quartz grains did not resemble those found in surface soils; instead, they displayed no evidence of smoothing or transit. Only at depths can one find such grains (B).

➔ A finely-grained, pinkish-yellow substance appeared to be a combination of clay and iron oxides (C).

➔ The small white shards resembled weathered zones that are deep below the surface and rich in kaolinite, like a quarry or mining area (D).

➔ The dirt lump (E) shows the actual sizes of the small white fragments. The absence of plant-derived organic matter indicated that the soil came from a lower layer. Low pH (acid) and low electrolyte concentrations (low salt levels).

Examination:

➔ Using relevant data and soil and geological maps, investigators and soil scientists examined the Oakbank Quarry in the Adelaide Hills.
➔ The materials from the quarry had a colour and texture similar to the soil on a shovel. Samples were gathered.
➔ Dr. Fitzpatrick and X-ray specialist Mark Raven analysed samples from the shovel and the quarry back at the CSIRO lab using X-ray diffraction techniques (see Figure 5).
➔ Similar to fingerprints, the composition of the samples' talc, mica, kaolinite, and quartz matched.
➔ Dr. Fitzpatrick was certain that the remains would be in the quarry's moist section. A detective came back every day, thinking that foxes may discover the bodies

Conclusion of the study: According to forensics, the dirt originated from a commercial gravel quarry, most likely in an Adelaide Hills area that was low in salt and acidic. A large puddle of water was discovered by foxes exposing a human hand after a few days, and the forensic team had already located that location. The next day, a second body was discovered fifty metres away. The suspect then admitted to the crime and was found guilty of murder.

Case Study 2: Murder of wife by her husband: A man was discovered in his tractor-trolley with a deceased female corpse. When the police came across him, they arrested him and asked him relevant questions. He was unable to react adequately, so the police dispatched a forensic team to look into the scene (Sharma, 2023).

Initial examination: When forensics experts arrived at the scene, they discovered that the victim's lifeless body was heavily attached to the earth. They searched a potential hiding spot for the corpse. After then, we found the spot where the dead body was hidden when we went to the home of the victim and the suspect.

Detail examination:

The room floor had a dip that was three feet deep, and freshly dug soil had filled it in. The victim's home, where her body was hidden, as well as the earth surrounding her body were submitted for examination. The soil from the place where the victim was hidden was the same soil that was removed from her body and examined in our laboratory. The man, who had been a barrier for another woman, acknowledged to the police that he had committed the crime to hide his adulterous affair. Thus, he killed her (Kaur et al., 2020).

The conclusion from the investigation: In forensic science, method result analysis compares soil specimens according to soil texture, colour, and particle size. The earth's soil is unique due to its diversified character, which includes variances in density, particle size, and soil changes caused by weathering and temperature fluctuations. Examined are the small particles' microscopic characteristics. It is hoped that this study will support and enhance the application of soil analysis in forensic science to uncover the real motives behind crimes and for investigative objectives.

With the aid of cutting-edge technology and expertise, several scientists have been developing ever-more-novel methods for identifying soil and comparing samples taken from criminals to establish a link between the soil and criminal activity. For the following reasons, even if it has lost value, it should be shown in court:

- public ignorance regarding the need to protect the crime scene.
- insufficient cognisance and understanding among pertinent parties.
- inadequate evidence handling practices when managing crime scenes.
- inadequate facilities for sample transportation to the forensic laboratories.
- contamination that occurs during sample collection and handling.

- Technology availability within the period frame.
- insufficient instruments for everyone.
- When starting an inquiry into a crime, law enforcement officials in this situation need to give soil collection more weight.

7. Conclusion

Expertise in soil science, forensic science, and criminal investigation is necessary for the highly specialised discipline of soil forensics. Forensic scientists can provide vital evidence for criminal proceedings and aid in the prosecution of offenders by methodically evaluating soil sample analysis. Because it offers insightful information and important evidence, soil analysis is essential to criminal investigations. As demonstrated by the history of case studies, soil can be crucial evidence in a forensic inquiry. Since it is just as unique as a human fingerprint and changes with evolution in the composition of soil, this is a very useful piece of evidence. It has the intricate structure of living things with many facets. The highly particular and intricate structures allow for excellent tracking of the offender if they are discovered promptly and with care.

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