International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume:03, Issue:01

ASSESSMENT OF SOIL BULK DENSITY USING GAMMA RAY SPECTROSCOPY

[1*]ADNAN LAHHAM; [1,2]ALA' THAWABTEH; [1,2]HUSSEIN ALMASRI

[1]Al-Quds University, Center for Radiation Science & Technology, Jerusalem, Palestine

[2]Al-Quds University, Medical Imaging Department

ABSTRACT

This study deals with a method nuclear technique method utilizing Gamma Ray Spectroscopy for the assessment of material bulk densities, specially soil density. The spectroscopy system consists of; 3" × 3" inch scintillation NaI(Tl) detector connected to multichannel analyzer Inspector 2000 from Canberra instruments and a laptop computer, ^{137}Cs radiation source and four different bulk materials with known densities. To calibrate the spectrometric system, detector and radiation source were placed in direct contact with the surface of the bulk materials located in wood boxes manufacture for this purpose. The distance between the radiation source and the detector varies from 10 cm to 30 cm. The Radiation source was shielded so that the emitted photons from the source travel in direction perpendicular to the top surface of the bulk material, and therefore the detector will register photons interacting with the material and scattered towards it. A relation was established between the density of the materials used for calibration and the count rate in different parts of the gamma ray spectrum, the full energy peak, the region of expected backscattering peak (from 50 Kev to 250 Kev), and the region containing Compton's continuum and the full energy peak as well. Actual field measurements on Terra Rosa soils showed that, the best results of bulk density evaluation were obtained when the detector and the radiation source are separated by 20 cm distance. Based on which parts of the spectrum are used for data analysis, the differences in bulk densities measured in the field and real values varies between 0.5% and 6%.

Keywords: Bulk density, soil, Gamma ray spectroscopy, nuclear techniques, in-situ methods

1. INTRODUCTION

Nuclear techniques have proved to be very useful in many branches of science and technology. The growing development of these technologies has provided appropriate solutions for many problems in life sciences and material sciences as well. Nuclear technique as a sensitive means of detecting information on different materials can hardly be replaced by other sensing methods; therefore, it holds a very important position among techniques for information acquisition. In agriculture, nuclear methods have many applications including and not limited to the study of soil water nutrients stage, soil erosions, texture, moisture and other soil physical characteristics. Important advantages of these methods in soil studies are that, they are non-destructive methods and can be applied directly in the field and therefore provide instant information for modern agricultural management practices.

Soil bulk density plays an important role in determining if the soil has the physical characteristics that necessary for plant growth, building foundations or other uses. In soil science, measuring soil bulk density will enable the calculation of other physical and chemical properties. By evaluating soil bulk density, we can calculate soil compaction and porosity. Compaction is a change in soil structure, not just an increase in soil density. An increase in bulk density indicates also, that movement of air and water within the soil has been reduced, and that the soil may be less favorable for plant growth or be more likely to erode so knowing soil compaction is important in agricultural activity. (Miller. R. et al, 2001) (Saly D. Logsdon, Douglas, L. Karlen 2004).

Soil content alters the soil bulk density, bulk density takes into account the total soil volume (the space occupied by the solid particles plus the space occupied by the air of the pores or pore space), it highly depends on soil moisture, compaction, texture, depth and mineral and organic material content (Brady, N. and R. Weil. 2002). For example, sandy soil has high density because of its texture with low pore spaces and the absence of organic material (which have low density). Sandy soil bulk density ranging from 1.2 to 1.8 g /cm^3. In another soil type, as clayey or silt soils have lower bulk density, it can be low as 1.1g/cm^3. Because of high organic material content, pore spaces and high degree of aggregation in its texture. Soil bulk density ranging from 1.0 to 2.0 g/cm^3 (Bouma. J, 1982).

Several methods are used to evaluate soil bulk density; conventional sampling methods and radiation methods. All sampling methods depend on taking the sample from the field to the laboratory, measuring its dry mass, then measuring its volume. The bulk density measurement should be performed at the soil surface and /or in a compacted zone if one is present. To get more representative soil bulk density measurements of the area, additional samples may be taken. Sampling methods are time consuming and destructive, so repeating the sampling procedure for the same site is impossible.

In general, there are two methods utilizing radiation technologies in soil bulk density determination; gamma ray transmission method (based on the attenuation of gamma photons passing through the soil sample), and gamma ray backscattering method (Thomas B., May 2001). Transmission method is easy, fast and accurate but it has a disadvantage that it is need a hole to dig so, it is partially destructive and the operator should know the mass attenuation coefficient, and the thickness of the absorber material.

Gamma ray backscattering spectroscopy method used the Compton scattering of gamma ray photons in bulk material to measure density. Since probability for Compton scattering interaction with matter is proportional to the number of electrons (atomic number of the material Z), the backscattered count rate depends on the density of the material. As the density of the material increases, the number of absorbed and scattered gamma rays increase and the number reach the detector decrease. A relationship then exists between the detected gamma radiation backscatter or and the density of the material (Nuclear Gauge Testing Manual 2016). Technically, backscatter method involves placing the radiation source and detector on the same side of the material to be measured (i.e. on the surface). Gamma radiation emitted from the source must then be scattered back towards the detector if it is to be detected (Ball. A, 1997). Such devises are widely used in well logging, soil and the manufacturing and construction industries. Backscatter density gauges can be applied to semi-infinite bulk materials (such as rock or soil), boreholes or structures where the other side is inaccessible (the walls of long tubes, for example).

The aim of this work is to present a method for the assessment of soil bulk density based on gamma ray spectroscopy.

2. MATERIALS AND METHODS

The system proposed for bulk density measurement used in this work consists of the following parts: a large volume NaI(Tl) scintillation detector (3” X 3”) inches connected to a multichannel analyzer (InSpector 2000) from Canberra and a laptop computer. The radiation source used is ^{137}Cs, photon energy 662 Kev and activity of about 30 KBq. This source is ideal for density measurements; first it is a monenergistic source of gamma photons. It is desirable to use radioisotopes that emit mostly at a single energy; otherwise, source photons would encounter differing interaction cross- sections. The detector cannot distinguish between photons which, when originally emitted, had different energies (Ball 1997). On the other hand, the activity is quite high to provide good counting statistics within a very short measuring time which limits the effect of background radiation. Also, the energy of emitted gamma photons is appropriate for penetrating the ground to an extent, so that to include as much as soil volume in the measurement process. What is also important, is that, for this energy the main cross-section of interaction with matter is Compton scattering. Figure 1 presents the basic components of the system and illustrates the geometry of measurement. The radioactive source is shielded with lead container. In backscatter technique, the shielding of the source is essential, to prevent photons from passing directly to the detector. Photons must interact first with the material under investigation and then part of them will be detected by the detector after being absorbed or attenuated in the bulk material. The detector response in this case will be a function of the density of the bulk material under test. This response is a complex spectrum typical for gamma rays interacting with matter and consisting of two main parts: Compton continuum and full energy peak. The shape of the spectrum; the number of photons fully absorbed by the detector or and the number of the scattered photons depends on the material the photons are interaction with. In principle, the whole spectrum holds information about the material, the gamma rays interact with. To study the relationship between the gamma ray spectrum and bulk material density; calibration spectra were measured over boxes containing materials with known bulk densities. The boxes were constructed from wood especially for this purpose according to (Regimand, A., (1997). Each box is 59 cm in length 42, cm in width, and 34 cm in height.

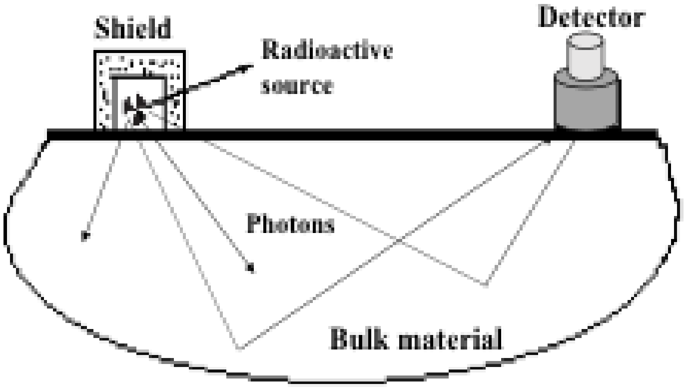


Figure 1: Basic components of the spectroscopy system – Geometry of measurement

3. RESULTS AND DISCUSSION

Prior to performing field measurements of bulk densities, a calibration procedure was conducted using four materials with known bulk densities (fine lime, Terra Rosa soil, pulverized lime stone and dry sand). Each material is located in a wood box as described above. Boxes are big enough to situate the gamma source and the scintillation detector with a distance, which protect the maximum of gamma ray from escaping from the box. Figure 2 shows two calibration spectra of ^{137}Cs measured under the same conditions as shown in figure 1, distance between the source and the detector is 20 cm. One spectrum is measured over a calibration box containing Tera Rosa and the other one over a box containing dry sand. In the regions of the two main parts; the two spectra are different in the number of registered photons. In the low energy region of the spectrum (from 0 to about 250 Kev) the spectrum of gamma rays interacting with sand shows higher number of scattered photons (in the energy range from 50 Kev to 250 Kev; the count rate of scattered photons in sand is higher than the count rate in the terra Rosa spectrum). The spectrum in the low energy region is more deformed in sand than in Terra Rosa. On the contrary, the count rate in the Terra Rosa spectrum full energy is about 1.3 times the count rate in the gamma ray spectrum from sand.

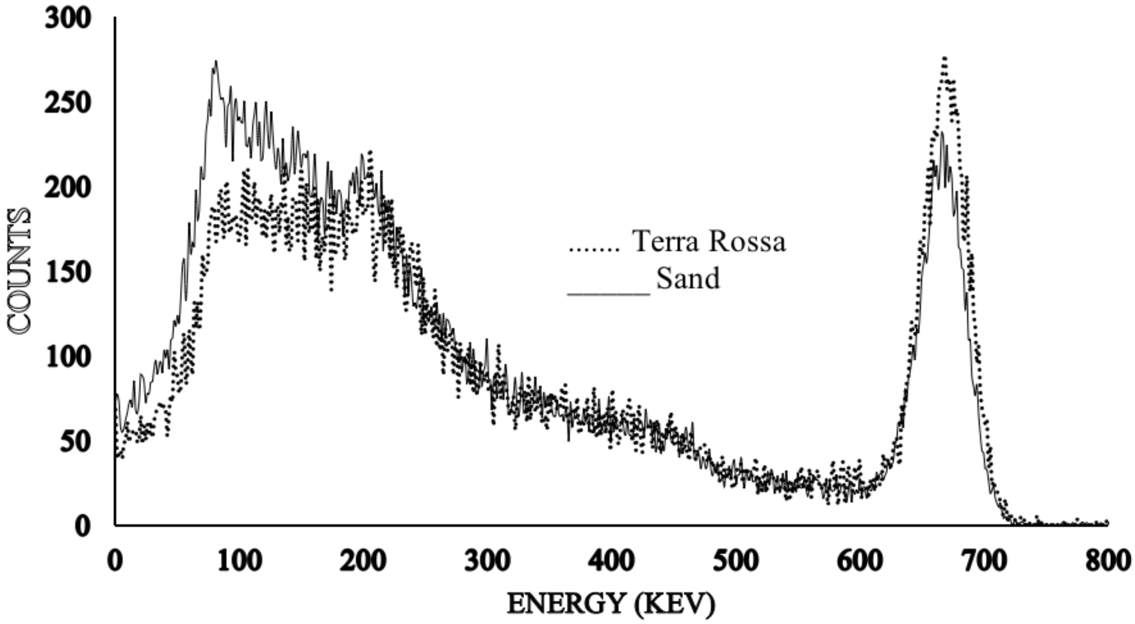


Figure 2: Spectra of ^{137}Cs measured on calibration boxes containing Terra Rosa and Sand; the distance between the source and the detector is 20 cm.

This can be explained as follows: sand is denser than Tera Rosa, which means that incident photons from the source will have more chances to be scattered on electrons of the sand and reach the detector with lower energies of scattered photons. Because of high number of electrons in the sand (higher density) fewer photons will pass the material and deposit all its energy in the full energy in the detector, and therefore less of them will be registered in the full energy peak of the spectrum. In other words, they will lose most of their energy in the backscattering region before reaching the detector.

Calibration on all bulk materials were conducted at different distances between the detector and the radiation source. Figure 3, illustrates the spectra of ^{137}Cs collected on the surface of sand material in wood box at different distances between radiation source and the NaI(Tl) detector (10, 15 and 20 cm).

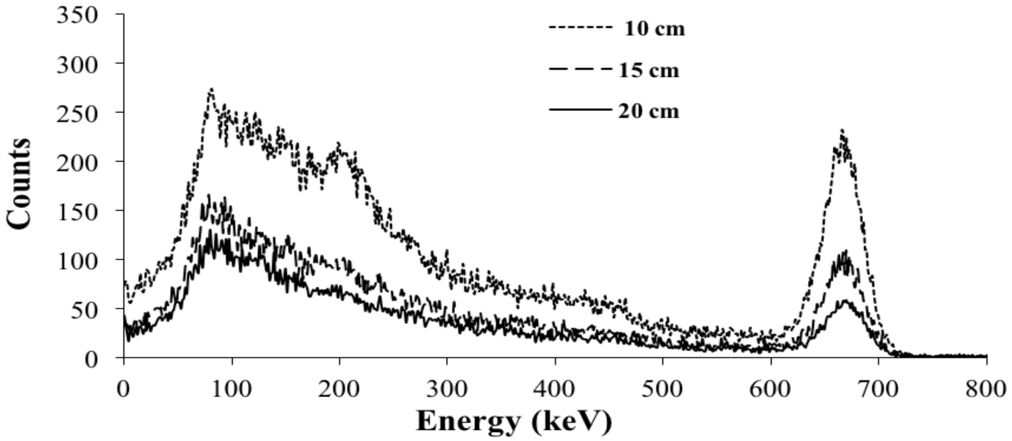


Figure 3: Spectra of ^{137}Cs collected over a wood box containing dry sand at various distances between the detector and the radiation source.

As stated above, all parts of the gamma ray spectrum hold information about the bulk material; mainly the region of backscattering peak and the Compton's continuum. Because the full energy peak is better defined than the Compton's continuum; it is better to find a relationship between the density of the material and the count rate in this part of the spectrum. The denser the material, the fewer gamma ray photons will reach the detector and being fully absorbed within it. This relationship was established using four different known bulk materials densities as shown in figure 4.

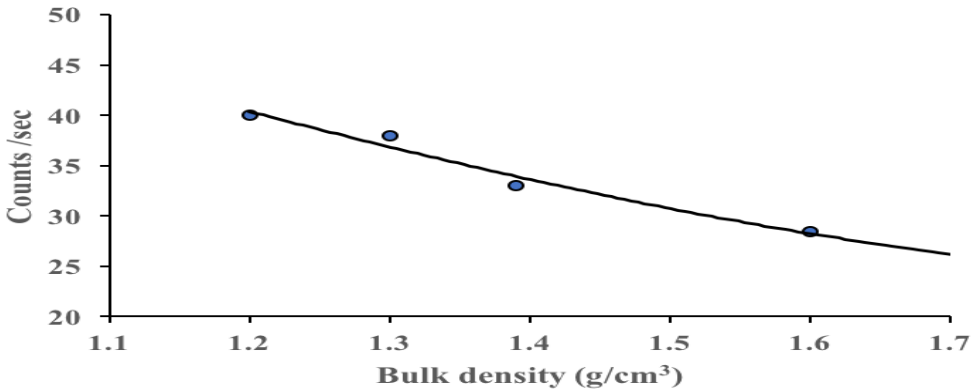
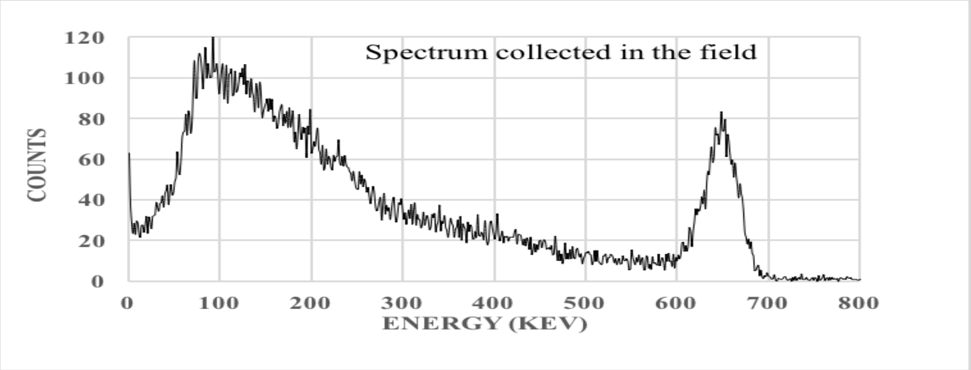


Figure 4: Count rates in the full energy peak as a function of material bulk density. Source detector distance is 20 cm.

Field measurements on Terra Rosa soil with data analysis based on these calibrations and source to detector distance of 20 cm are in very good agreement with real values of the Terra Rosa densities. Figure 4 illustrates a comparison between two spectra of ^{137}Cs collected at the surface of a Terra Rosa land (in the field), one spectrum is collected over a calibration box and the other is collected in the field at 20 cm separation distance. Nearly both spectra are identical indicating the precision of our measurement and the reliability of the proposed method. The net peak areas in both cases varies within about 0.5%. In case of assuming the whole spectrum (the total area of the spectrum), field results are overestimated by about 5%. It was found experimentally that; the best results of bulk density measurements are obtained when the separation distance between the detector and the source of radiation is 20 cm. In this case, larger volume of the bulk material is considered, furthermore the fluctuation of spectrum and the background is limited and can be better identified.



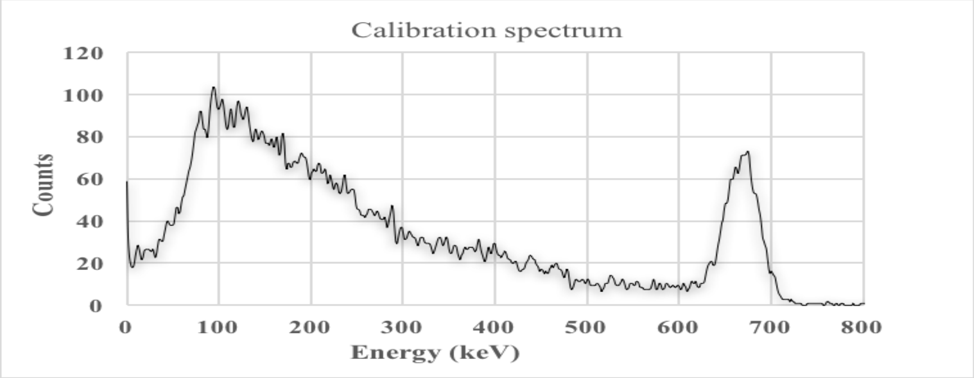


Figure 5: Spectrum of ^{137}Cs collected over a Terra Rosa land; upper spectrum is collected in the field, the lower one is a spectrum collected over a calibration wood box containing Terra Rosa of known bulk density.

Other parts of the spectrum were also studied, the backscattering peak region which is expected for ^{137}Cs in the energy region of about 180 Kev. The energy region from 50 to 250 Kev was investigated for a relation with the bulk density of the material. As this part and the full energy peak are the main two part of the spectrum affected by the density of the bulk material, we have investigated a relation between the count rates in these parts and the density of the bulk material. Figure 6 presents a linear relationship between the ratio of the count rate in the full energy peak and the backscattering peak (energy range from 50 – 250 Kev) and the material bulk density being tested.

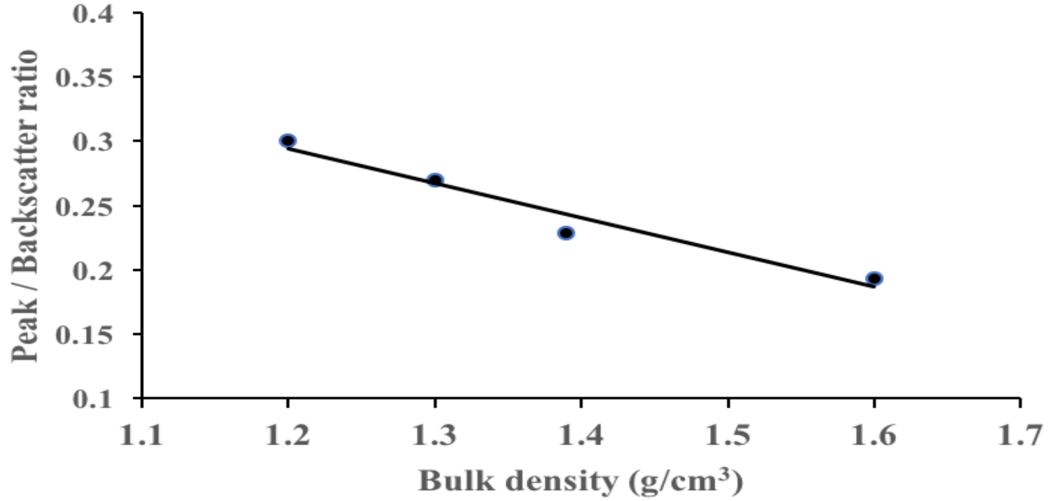


Figure 6. Relationship between peak to backscattering count rates ratio (energy range from 50 – 250 keV) and bulk density. Source detector distance is 20 cm.

The field measurements of bulk density of Terra Rosa using this relationship gave an overestimated bulk density by about 6 %. We have also investigated a method which take into account the whole spectrum from 50 Kev to about 730 Kev. In this case the measured field bulk density was overestimated by about 5%. Also, the part of the spectrum from 250 to 730 Kev considering both Compton's continuum and full energy peak. This method overestimated the bulk density of Terra Rosa by about 6% too. The overestimated values of bulk density in field measurements result from the roughness of the surface of the soil in the field in comparison of the smoothed and homogeneity of bulk materials used in the calibration process.

4. CONCLUSION

Gamma spectroscopy is a powerful tool in many applications, measuring of material bulk densities is not an exception. This work demonstrated clearly how much considerable information we can obtain from one single gamma ray spectrum. The proposed method is simple, non-destructive, sensitive accurate and can be used for the assessment of bulk densities of different materials. By using this method, we can study more physical characteristics of the soil particularly since bulk density is related to many of these characteristics. This will be our future research concerning this issue.

REFERENCES

Miller, R. E., J. Hazard, et al. (2001). Precision, accuracy, and efficiency of four tools for measuring soil bulk density or strength. Portland, Oregon, USDA Forest Service, Pacific Northwest Research Station: 16.

Saly D. Logsdon, Douglas, L. Karlen (2004): Bulk density as a soil quality indicator during conversion to no-tillage. Soil & Tillage Research 78 (2004) 143–149

Brady, N. and R. Weil. (2002). The Nature and Properties of Soils, 13th Edition. Prentice Hall. Upper Saddle River, New Jersey.

Bouma J., P.S.C. Rao, and R.B. Brown (1982): Basics of Soil-Water Relationships -Part III. Movement of Water. Soil Science Fact Sheet SL-39. Florida Cooperative Extension Service. IFAS. Gainesville, FL.

Thomas B., May Thomas, B., Randrup and John M. Lichter., (2001). Measuring Soil Compaction on Construction Sites: A review of Surface Nuclear Gauge and Penetrometers. Journal of Arboriculture 27(3).

Nuclear Gauge Testing Manual (2016), Technical publication, Edition 3; Dept. of Transport and Main Roads, Queensland Government

Ball, Andrew Jonathan, (1997), Measuring Physical Properties at the Surface of a Comet. PhD thesis. University of Kent, Canterbury UK.

Regimand, Ali, (1997). Validation and calibration apparatus and method for nuclear density gauges. US Patent number 5,923,726.