DEVELOPMENT AND EVALUATION OF UNDISTURBED SOIL SAMPLER FOR SOIL CORE ANALYSIS

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Abstract: Soil sampling and testing are vital operations in the field of agronomy and geotechnics; as they are important means by which soil fertility and changes taking place within soils subjected to structural loads can be assessed. Also, the most reliable means by which the integrity of reclamation or remediation practices on soils can be assessed is by sampling and testing. However, the reliability of soil samples as true representation of the soil natural state depends on the nature of the undisturbed soil sampler used. In this study, undisturbed soil sampler was designed, fabricated and tested to provide an index for the soil core analysis in terms of the soil's bulk density. The undisturbed soil sampler was fabricated by using a combination of 5 mm stainless steel and mild steel plates and operates on the principle of impact induced by screw jack. The sampler was tested on the field of the Faculty of Engineering in terms of the variability of the soil's bulk densities with different depth ranges of the soil profile. Such results will help in validating the reliability of soil samples obtained with the undisturbed soil sampler, as a true representation of the condition of the soils in the site. This will provide accurate soil test results in terms of the determination of engineering properties of such soils *in-situ*.

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1. Introduction

Sampling of soil for analytical purpose is very important in such field of studies like geotechnics, agronomy and hydrology. This is because investigating soil properties prior to either their utilization or post treatment approaches in these fields; determine the overall benefits derivable from the soil. However, the soil sample protocol and integrity are dependent on the nature of the sampler employed. Assessing soil's properties in the field tend to be difficult, unreliable and capital intensive; hence the needs for sampling for laboratory scale investigation before up scaling to field condition (DeGruijter *et al*., 2006).

Soil samples can be of two types: disturbed and undisturbed samples. A disturbed sample is that in which the natural structure of soil gets partly or fully modified and destroyed although with suitable precautions, the natural water content may be preserved. Such a soil sample should, however, be representative of the natural soil by maintaining the original proportion of the various particles intact. Undisturbed soil samples retain the structural integrity of the in-situ soil and have a high recovery rate within the sampler (DeGruijter *et al*., 2006). Collecting a perfectly undisturbed soil sample is difficult and the samplers may contain a small portion of undisturbed soil at the top and bottom of the sample length (Batjes, 2016). Undisturbed Soil sampling and testing provides an excellent inventory of plant available nutrients and other soil factors important for crop production.

Core samplers are a common method of obtaining soil samples for bulk density measurements. These devices comprised long tubes that are either hammered, driven at a constant speed, or augered (Raper and Erbach, 1987). The soil removed from these long tubes can be analyzed in sections for bulk density measurements. Although in common use, these devices are not perfect. Soane (1976) concluded that the core sampling method may have larger errors than the gamma-ray method.

In another study, Baranowski (1983) investigated whether estimates with conventional core sampling could secure data of desired accuracy. The researcher found, under favorable conditions even with careful sampling procedures and a sufficient number of replications, that the core method produced inter-treatment densities to accuracies no greater than $0.05 mg/m^3$. When the conditions are not as favorable, he mentioned that the error can be as much as five times greater. Compaction of the core seems to account for the largest error inherent to core sampling devices. As the tool is pushed or augered into the ground, very little disturbance seems to occur across the core, but variations in length are found (Raper and Erbach, 1988). Raper and Erbach, (1988) noted that narrow sampling tubes tend to compress the core. The researchers advised using at least a 7.6.cm diameter tube to minimize compression.

The design of the core sampling device greatly affects its accuracy. A taper inside the tube, starting from the tip and extending back up into the core sampler provides clearance between the soil core and the inside of the soil tube. Soil will be compacted only outside of the sampler where it will not affect the sample (Raper and Erbach, 1987).

To remove a soil core from a sampling hole, a certain normal force must exist between the soil sampler and the soil column. This frictional force should, however, be small to minimize compaction of the soil core. If this force is excessive, large deformations of the soil core near the edges can be expected. Coating the soil corer tip with a slippery substance, such as oil reduces the frictional force on the soil column. This lubricant, ideally, does not affect the moisture content or chemical composition of the soil sample nor does it decrease the frictional force below that necessary to remove the soil sample from the sampling hole (Raper and Erbach, 1987).

Research is needed in two areas to reduce the error associated with core samples: to develop core sampling methods that minimize compaction of the soil core and to determine if the frictional force necessary for removal of the soil core from the ground could be reduced (Raper and Erbach, 1987).

The standard soil sampling for undisturbed soil samples for assessment of soil bulk density, water retention capacity, infiltration capacity and other physical parameters are usually done by hammering of metal cylinders down into the soil with subsequent excavation. The mechanical stress, however, which is exerted during the hammering procedure of metal cylinders with a hammer leads to deformations at the sample walls, so that no real undisturbed sample is achieved.

The pushing of metal cylinders into the soil without greater power and thus without soil disturbance is only possible when the soil is nearly saturated (near field capacity) or else in very loose soil, for example after ploughing. But soil sampling is also necessary during dry periods since the annual dynamics of soil structure is important for the understanding of soil turnover processes. Therefore, new methods are required for the sampling of undisturbed soil cores. It is against this background that this project seeks to design, fabricate and test a reliable undisturbed soil sampler to address issues bordering use of soil sampler and sampling techniques of undisturbed soil. In this context, a sufficient number of samples, a high temporal resolution of sampling and samples from a large number of different soils are needed for a thorough analysis of soil structure with a statistically relevant validation of results. The objective of this research is to develop a reliable undisturbed soil sampler suitable for collecting undisturbed soil samples from different site locations for soil core analysis.

2. Materials and Methods

2.1 Design considerations for the undisturbed soil sampler

In other to construct an effective undisturbed soil sampler, following considerations will be taken into account in designing and choosing the materials for fabricating the sampler:

i. Strength of the material. The ratio of the strength relative to weight of the material must ease the movement or transportation of the tool.
ii. Cost and availability of the material. The material should be available and locally sourced.
iii. The tool should be simple and easy to use.
iv. It should be capable of reducing drudgery during operation.
v. The cost of maintenance of the sampler should be low.
vi. The efficiency of the hand tool should be up to 80-90% if not 100%.

After these listed assumptions are met, the physical properties of the materials should be strong enough to withstand various vibration and stresses without bending or twisting during operation.

2.2 Design conception

The machine will consist of four segments; the cutting segment, screw segment, power segment and the frame. The cutting segment consists of the cutting cylinder which will be made of mild steel; the screw segment consists of the crew shaft and the boss; the power segment consists of the rotary handle while the frame serves as a support and stand for the machine on which all other segments will be mounted.

2.3 Description of the undisturbed sampler components

The major components of the undisturbed soil sampler include: the cutting cylinder (tube), the rotary handle, boss and frame. Each of these components is described as follows:

The cutting cylinder (tube): The cutting cylinder comprises of a down shoe or cutting edge which is fastened directly to the handle of the sampler. The cutting cylinder is forced into the soil by screwing it through a threaded boss or guide cylinder to collect the soil sample.

The handle: The handle made of a rod with a crossbar handle is used to rotate the cutting cylinder (tube) during soil sampling. The rotation of the handle drives the cutting cylinder into the soil.

The boss: The boss is a heavy hexagonal iron rod threaded in the inside to serve as screw for driving the cutting cylinder into the soil.

The frame: The frame is the part of the sampler that supports all other components of the sampler.

2.4 Design calculations

The design features that affect sample disturbance include; area ratio, inside clearance, outside clearance, recovery ratio, inside wall friction, design of non-return value, method of applying force, sizes of sample tube.

Design of the rotary handle

The weight of the rotary handle was obtained from the Equation recommended by Tanko and Boman (2017);

$W_h = \rho_h V_h g$ (1)

But $V_h = \pi D_h T_h L_h$ (2)

Where; ρ_h = Density of handle (kgm^{-3}), V_h = Volume of handle (mm^3), D_h = Diameter of handle (mm), T_h = Thickness of handle (mm), L_h = Length of handle (mm).

Design of the screw shaft

Weight of the screw shaft: The screw shaft was made of a hollowed cylindrical shaft of length 677 mm, diameter 40 mm and thickness 5 mm. The screw shaft was designed to have a screw length of 487 mm with 60 screw turns, screw pitch of 8 mm and screw height or depth of 3 mm. The weight of the shaft was calculated from Equations 3 and 4 (Tanko and Boman, 2017).

$W_s = \rho_s V_s g$ (3)

But $V_s = \pi D_s T_s L_s$ (4)

Where; ρ_s = Density of shaft (kgm^{-3}), V_s = Volume of shaft (mm^3), D_s = Diameter of shaft (mm), T_h = Thickness of shaft (mm), L_s = Length of shaft (mm).

Load that can be lifted by the screw: From design assumptions, a force of 210 N can be applied by a man at a speed of 60 rpm and at a distance 0.2m from the axis and tangential to the shaft (Gbasouzor and Nwanekezie, 2016). The angle of friction was calculated from Equation 5 (Istifanus *et al.*, 2022).

$\theta = \tan^{-1}\mu$ (5)

Where; θ = angle of friction, degrees, μ = coefficient of friction (0.466).

The load that can be lifted by the screw was determined from Equation 6 given by Khurmi and Gupta (2008) as;

$W = \frac{P}{\tan(\alpha+\theta)}$ (6)

Where; W = Load that can be lifted by screw (N), P = Effort applied at the circumference of the screw to lift the load (N), α = Helix angle (Degrees), θ = Angle of friction (Degrees).

Pressure to be developed by the screw thread: Screw area was calculated from equation 7 (Hall *et al.*, 1980).

$A_p = \pi D_m nh$ (7)

Where; A_P = Screw area (mm), D_m = Mean thread diameter (mm), n = Number of screw turns in the boss or nut, h = Screw depth (mm).

The pressure developed by the screw thread was determined from Equation 8 (Hall *et al.*, 1980).

$P_r = \frac{W}{A_p}$ (8)

Where; P_r = Pressure developed by the screw thread (N/mm^2), W = Load that can be lifted by the screw (N), A_P = Screw area (mm^2).

Design of the cutting cylinder

The cylinder is a drum with one end closed and the other end open. The closed end has a hole at a point to serve as the non-return valve and the open end is sharpened to facilitate entrance into the soil.

Weight of the cutting cylinder (W_c): The weight of the cutting cylinder includes the weight of the cylinder and the face plate.

Weight of the cutting cylinder was calculated from Equation 9 (Hannah and Hillier, 1999).

$W_c = \rho_c V_c g$ (9)

But $V_c = \pi D_c L_c t_c$ (10)

Where; ρ_c = Density of cutting cylinder (kgm^{-3}), V_c = Volume of cutting cylinder (mm^3), D_c = Diameter of cutting cylinder (mm), L_c = Length of cutting cylinder (mm), t_c = Thickness of cutting cylinder plate (mm), g = Acceleration due to gravity (m/s^2).

Weight of the face plate was obtained from the Equation;

$W_p = \rho_p V_p g$ (11)

But $V_p = L_p B_p T_p$ (12)

Where; ρ_p = Density of face plate (kgm^{-3}), V_p = Volume of face plate (mm^3), L_p = Length of face plate (mm), B_p = Width of face plate (mm), T_p = Thickness of face plate (mm).

Shear failure analysis of cutting cylinder: The shearing stress of the cutting cylinder is defined by Khurmi and Gupta (2008) as;

$\tau = \frac{16M_t}{\pi d^3}$ (13)

The torque was found from Equation 14 (Khurmi and Gupta, 2008);

$M_t = FR$ (14)

Where; τ = Shearing stress (N/mm^2), M_t = Torsional moment (Nmm), d = Diameter of the cutting cylinder = 78mm, F = Force to turn the cutting cylinder (N), R = Turning diameter of the rotary handle (mm).

Area ratio

For obtaining good quality undisturbed samples the area ratio should be less than or equal to 10 percent. It may be high as 110 percent for the thick wall sampler like split spoon sampler and may be as low as 6-9 percent for thin wall sampler like Shelby sampler

$\text{Area ratio} = \frac{\text{Max. cross sect. area of cutting edge}}{\text{Area of the soil sample}}$ (15)

$A_r = \frac{D2^2 - D1^2}{D1^2} \times 100\%$ (16)

Where; D1= inner diameter of the cutting edge (mm), D2= outer diameter of the cutting edge (mm).

Recovery ratio

The recovery ratio was calculated using Equation 17.

$R_r = \frac{L}{H}$ (17)

Where; L= Length of the sample within the tube (mm), H = Depth of penetration of the sampling tube (mm). R_r = 96-98 percent for getting a satisfactory undisturbed sample.

Inside wall friction

The friction on the inside wall of the sample tube causes disturbance on the sample. Therefore, the inside surface of the sample should be smooth as possible. It is usually smeared with oil before used to reduce friction.

Design of non-return value

The non-return value provided on the sampler should be of proper design. It should have an orifice of large area to allow air, water or slurry to escape quickly when the sampler is driven. It should close when the sample is withdrawn.

Method of applying force

The degree of disturbance depends on the method of applying force during sampling and depends upon the rate of penetration of the sample. For obtaining undisturbed sample, the sampler should be pushed and not driven.

Design of pulling force required to raise the sampler

The pulling force of sampler consists of the force required to raise the total weight of the sampler (weight of frame, handle, screw shaft and cutting cylinder) and the force resulting from the shear stress of the soil sample. The force resulting from the shear stress of the soil sample was calculated from Equation 18 (Khurmi and Gupta, 2008).

$$F = \tau \times A_c \quad (18)$$

But $A_c = \pi D_c L_c \quad (19)$

Where; F = Force resulting from the shear stress of the soil sample (N), τ = Shear stress of soil sample (N/m^2), A_c = Curved surface area of cutting cylinder (mm^2), D_c = Diameter of cutting cylinder (mm), L_c = Length of cutting cylinder (mm).

2.5 Material selection and assembly

Stainless Steel: It was used for the construction of the cutting cylinder; it is made with stainless steel because it has greater strength and can easily be welded. It can easily be sharpened when blunt for the cutting edge. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environment.

Mild steel: It was used for the handle, boss and frame because it requires a reasonable strength and high rigidity.

Electrodes: these are welding material use during welding and the sizes vary from 6mm - 12mm.

2.6 Fabrication process

Fabrication was carried out at the Central Engineering Workshop of Faculty of Engineering, Taraba State University, Jalingo, Nigeria. The cutting cylinder was fabricated from a stainless-steel of 5 mm thickness. The handle was fabricated from a mild steel shaft, cut to sizes and welded. The frame was fabricated using rectangular mild steel bars and the boss was made using a thick mild steel shaft.

2.7 Operation of the sampler

To operate the sampler (Plate 1) the soil must first be carefully levelled at the required depth from the surface. The sampler is then placed on top of the soil and the cutting cylinder inserted in the boss with the ends of the small rod engaged in the spiral grooves. The Operator stands on the base plate and rotates the cutting cylinder by means of the rod and cross bar handle. Little effort is required to screw the cutting cylinder into the soil.

Plate 1: The Undisturbed Soil Sampler

After the cutting cylinder has been screwed through the threaded boss until it is free under the base, the latter is lifted off, leaving the cutting cylinder in the soil. This is then carefully dug out with its contained sample, and the bottom surface on the sample is smoothed even with the cutting edge of the cylinder. The sample is then placed on the plunger which is slightly smaller in diameter than the cutting edge and is pushed upward out of the cylinder. The sample is now resting on top of the plunger and can be examined for disturbance before placing it in the container. Most tests can be performed on the sample without removing it from the container.

2.8 Testing of the sampler

The sampler was used to test the variability of a particular soil's bulk density with depth. The sampler was used to obtain soil samples from the Engineering Complex, Faculty of Engineering, Taraba State University, Jalingo. The bulk densities of soil samples obtained from different depths with the sampler were determined.

Bulk density is the ratio of mass of soil sample to its volume. The mass of soil sample was determined using an electronic balance and the volume of soil was calculated from the volume of the cutting cylinder. The bulk density was calculated by using the Equation below.

$$\rho = \frac{M}{v} \qquad (20)$$

Where; ρ = Density (kg/m^3), M = Mass of soil (kg), V = Volume of soil sample (m^3).

3. Results

The result obtained from the fabrication of the soil sampler that will be used to obtain undisturbed soil sampler for soil property analysis using manually operated mechanical screw shows that this process (mechanical screw) is the most suitable method for extracting soil sample because of its ease of operation.

The portable soil sampler was developed such that it can be used to obtain soil samples from soil profiles up to the depth of 0.368 m. It is able to extract soil samples in its whole volume at random depths within the design depth from soil profile. The assembling of the major parts of the portable sampler was made by using steel because of its durability and resistance.

The main components of the sampler include; rotating handle, boss, cutting cylinder and frame. These parts were fastened into a supporting frame. The sampler cutting cylinder was made of mild steel with a sharpened cutting edge, to minimize soil compaction compared to other types of samplers. The sampling tube (cutting cylinder) is typically attached to the sampler head or handles using electrode, gas welding or bolting.

The developed core sampler performed well during the soil sampling for soil density determination. Under the soil condition relatively good for sampling work, it took about 14 - 15 minutes to sample soil core from the surface to the depth of 60 cm by one person with the hand operated device. The sampling time is only about a half of the conventional soil sampling method.

The laboratory experiments were carried out to compare each of the sampling depths and to eliminate all of the possible restrictive aspects affecting the procedure of measurement. There were different values of bulk density measured in depths of 0 - 60 cm in laboratory conditions because of different sampling depths. Those differences were becoming equal depending on the depth. Bulk density values simulated perfect existing conditions.

It was observed that the mean values of soil densities increased with soil sampling depth with minimum value of 1732.51 kg/m^3 at the depth of 0-15 cm and maximum value of 2896.35 kg/m^3 at the depth of 45-60 cm. This is in agreement with the work of Prikner *et al*. (2004) who investigated the soil bulk density at different soil profile and found that soil density increases with the depth of soil profile. These differences of measured values of both sampling techniques could be caused by soil profile conditions and the variance of moisture content in soil profiles (Prikner *et al*., 2004).

4. Conclusion

A portable and compact soil sampler has been developed and tested on level as well as sloping ground. In the field trials, good quality samples of colluvial soils have been recovered successfully from depths up to 60 cm. The soil sampling system developed has subsequently been used in the investigation soil density. Compared with conventional drilling and sampling methods, considerable savings in cost and time could be achieved by using the sampler.

It is recommended that further development work on the sampler be explored to enable the recovery of undisturbed samples at greater depths (say, up to 100 cm). The possible areas of improvement to the System to achieve this include:

(a) Provision of a drill casing to prevent hole collapse.

(b) Use of a percussive drill bit to overcome rock/boulders.

(c) Use of a lever and additional counter-weight to increase the downward thrust.

References

Baranowski, R. (1983). Evaluation of the useability of procedures for the determination soil physical properties in tillage experiments. Institute of Soil Science and Plant Cultivation, 55 – 230 LaskowiceOlawskie, Poland.

Batjes, N.H. (2016). Harmonised soil property values for broad-scale modelling (WISE30sec) with estimates of global soil carbon stocks. *Geoderma, 269: 61-68.*

DeGruijter, J., Brus, D.J., Bierkens, M.F.P. and Knotters, M. (2006). Sampling for Natural Resource Monitoring, volume 14. New York: Springer, Berlin, Heidelberg. 334 pp.

Hall, A.S, Holowenko, A.R. and Laughlin, H.G. (1980). Theory and Problems of Machine Design, SI Metric Editions, Schaum's Outline Series, McGraw-Hill Book Company, New-York, America. 344 PP.

Hannah, J. and Hillier, M.J. (1999). Applied Mechanics, Third Edition. Pearson education Limited, Harlow, England. 445 pp.

Istifanus, A.B.; Namessan, N.O. and Bako, T. (2022). Development of an Apparatus for Measuring Coefficient of Friction of Crops. *Taraba Journal of Engineering and Technology* (TAJET), 2(2): 6-9.

Khurmi, R. S. and Gupta, J. K. (2008). A textbook of machine design, 14th edition. New Delhi: Eurasia Publishing House (PVT) Limited, Ram Nagar, India, 1230 pp.

Prikner, P., Lachnit, F. and Dvorak, F. (2004). A New Core Sampler for Determination of Bulk Density in Soil Profile. *Plant Soil Environment*, 50 (6): 250-256.

Raper, R.L. and Erbach, D.C. (1987). Bulk Density Measurement Variability with Core Samplers. *Transactions of the American Society of Agricultural Engineers (ASAE)*, 30(4): 878 – 881.

Raper, R.L. and Erbach, D.C. (I988). Core sampler evaluation using the finite element method. *Transactions of the American Society of Agricultural Engineers (ASAE)*, 31(2): 331-336.

Soane, B.D. (1976). Gamma-ray transmission systems for the in situ measurement of soil packing rate. Report 1974 – 1976. Scottish Institute of Agricultural Engineering, Bush Estate, Penicuik, Midlothian, Scotland.

Tanko, B. and Boman, J.B. (2017). Design, Fabrication and Performance Evaluation of a Hand Operated Maize Sheller. *Journal of American* Science, 13(8): 68-76.