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A Study of the Moisture Content and Bulk Density of Soil in Relation to its Temperature Values: A Case Study of Soils Around Bosso Campus of the Federal University of Technology, Minna, Northcentral Nigeria

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Abstract

This study investigates the moisture content and bulk density properties of a sample of loamy soil obtained from the Bosso Campus of the Federal University of Technology, Minna, over a period of ten days. Moisture content and soil compaction studies are vital in agriculture on account of their effect on plant growth and yield because seedlings can only germinate under optimum conditions of moisture content and soil compaction. Loamy soil sample was collected, sun-dried, wetted, distributed amongst ten PVC tubes each 30 cm in height, and compacted. Each of the PVC tube was drilled at intervals of 2cm. Thermometers were inserted at the 16 cm, 18 cm, and 20 cm marks for each PVC tube and the average bulk density and moisture content were evaluated. The results obtained were subjected to the chi-square test and the Spearman Rank correlation test analyses and tested at 0.01 level of significance. The results indicate that there is no significant difference amongst the various mean temperature values at the different thermometer points; also strong positive correlations were observed between the mean temperature and the moisture content values on the one hand and between the mean temperature and the bulk density values on the other hand.

Keywords: Soil temperature, moisture, bulk density, test-statistic, degree of freedom

1.0 INTRODUCTION

This study investigates the physical characteristics (i.e., moisture content and bulk density) of a sample of loamy soil obtained from the Bosso Campus of the Federal University of Technology, Minna, in relation to its temperature over a period of ten days. Moisture content characteristics and soil compaction studies are vital in agriculture because of their effect on plant growth and yield. Seedlings can only germinate under optimum conditions of moisture content and soil compaction. Soil temperature plays a vital role in the general characteristics of any soil sample. It is known that most organic and inorganic processes occurring in the soil are strongly affected by temperature, and seeds will not germinate until soil temperature has reached a certain critical value. Soil temperature influences the functional activity of plant roots, such as the absorption of water and nutrients. The rate of growth and subsequent crop yield are related to the soil temperature status

(Dickson, 1985). Temperature also has a great effect on soil moisture, aeration, and structure of the soil, as well as microbial and enzyme activities in the soil. In engineering, the study and understanding of soil temperature assists in the area of construction like road design, building of pipeline for sewage, pipeline for water, underground cables, and construction of bridges. There is also this general belief that the soil absorbs excess heat from the atmosphere and gives off the heat at night thus making the soil act as a cooler by serving as a heat reservoir and climatic stabilizer (Arridsson, 1998; Carter, 1990; www.soilsciencejournals.org).The way soil behaves depends not only on the kinds and sizes of individual particles but also on how these are arranged and bonded together. Sometimes they occur as collection of single individual grains (as in sands) but usually they are linked into clusters or aggregates of varying stability. Clayey soil contains more pore spaces than sandy soil but they have a much smaller pore size. The pore size distribution controls water transmission (www.forester.net).

Compaction refers to the increase in density of soil as a result of applied load or pressure. This means that the soil has a certain density or state of compaction before the load or pressure is applied. In other words, soil compaction is dynamic soil behaviour. All soils are compacted to some degree. Some amount of soil compaction is necessary to support the plant, avoid drying and provide the seed-soil contact required for germination. It has been reported that soil compaction is caused by natural shrinkage of some soils upon drying and by farm machinery. The total volume of soil is made up of the volume of soil mineral grains, organic matter, and pore spaces. The pore volume is usually partially-filled with water and the rest is air. Soil is compacted when the proportion of total pore volume to total soil volume is inadequate for maximum crop growth or efficient field management. Heavily compacted soil contains few large pores and has a reduced rate of both water infiltration and drainage from compacted layers. This occurs because large pores are the most effective in moving water through the soil when it is saturated. In addition, the exchange of gases slows down in compacted soils, causing an increase in the likelihood of aeration-related problems. Soil compaction increases soil strength, and the ability of soil to resist being moved by an applied force. It implies that the root must exert greater force to penetrate the compacted layer (Smith, 1997). Also, Kirkham and Powers (1972) have defined soil compaction as the movement of soil particles (sand, silt, and clay) closer together due to external forces. The soil becomes denser and soil pores become smaller and increase in soil density results in higher strength and lower hydraulic conductivity. The types of soil compaction are deep soil compaction,

and surface soil compaction. A good soil for crop production contains 25% water and 25% air by volume. The remaining 50% consist of solids. Anything that reduces pore space results in a dense soil with poor internal drainage and reduced aeration (www.forester.net).

There are different schools of thought regarding the concept of soil moisture. Some authorities posit that soil moisture is available water in the soil while others (e.g., A.J. Odofin, personal communication) think otherwise. The major source of water supply for soil is mainly rainfall, part of which sinks into the soil. The rate at which water sinks into the soil depends on the soil texture and structure (King, 1992). Soil moisture influences the thermal properties of the soil. Soil with high water content warms up and cools down more slowly than dry soil. The amount of water in a particular soil gives the description of such soil as dry, damp, wet, very moist or slightly moist. There are several methods of determining soil moisture content, viz: time domain reflectometry (TDR), gamma ray, neutron scattering, and oven-drying methods. The commonest of the above-mentioned methods is the oven-drying method which involves drying a known amount of moist sample in an oven at constant temperature of about 105^0C. The oven-drying method was the one used for this work.

2.0 METHODOLOGY

Experimental set up: Loamy soil sample was collected from around the Physics and Microbiology laboratories. The sample was originally sun-dried for four days, and on the fifth day the sample was wetted by sprinkling water on it while stirring with spatula. Then the sample was divided amongst ten PVC (polyvinyl chloride) tubes in accordance with the Al-Nashabandi and Kohnke method, by which soil compaction was done at interval of every two or three spoonfuls of the soil sample as it was progressively being scooped into the tube. Compaction in this case was achieved by raising and gently hitting the tube on the floor. The ten PVC tubes, each of height 30cm, were drilled at 2cm interval; the holes created were for thermometers to be inserted. The top of each PVC tube was covered with a black polythene sheet held in place by a rubber band. This sheeting helped to prevent evaporation. After filling the tubes to the brim, three thermometers (0-100^0C range) were inserted at the 16cm, 18cm, and 20cm depth points in each tube. The weight and volume of each PVC tube were determined in order that the bulk density may be calculated. The PVC tubes containing the samples were exposed to the sun for heating in the open. The oven-drying method was employed to determine moisture content.

3.0 MEASUREMENTS

3.1 Soil temperature: It is required, at the start of measurement, to pour the soil sample on a flat surface and introduce moisture. A small amount of the moistened soil sample was collected in a tin cup and weighed. After weighing, the sample was then oven-dried at 105^0C. The difference between the wet and dried soil samples gave the amount of moisture present. The remaining wet soil sample was then re-packed into the PVC tubes, and thermometers were inserted at the 16cm, 18cm, and 20cm points. Hourly measurements of soil temperature were taken from 8.00 a.m. to 5:00 p.m. daily for ten days, giving a total of one hundred (100) hours of soil temperature readings. Since three thermometers were inserted in each of the PVC tubes, a total of three hundred (300) individual thermometer readings were taken each day for the ten PVC tubes. This translates to three thousand (3000) individual thermometer readings for the 10-day period.

3.2 Bulk density: The bulk density was determined from a measurement of the mass of each PVC tube plus soil and the volume of the tube. It is known that the density is mass divided by volume; the mass of each PVC soil sample tube was directly determined by use of a standard weighing balance, while the volume of each of the tubes was determined by using the formula for evaluating the volume of a cylinder, viz:

$$V_c = \pi r^2 h \qquad (1)$$

where r is the radius (i.e.3.7cm) of the cylinder and h is the height of the cylinder (i.e. 30cm).

3.3 Moisture Content: The oven-drying method was the preferred means of soil moisture content determination used for this work. The oven-drying method entailed taking a known weight of the moist sample, and drying the sample in an oven at a constant temperature of about 105^0C. The moisture lost by heating represented the soil moisture in the moist sample.

4.0 RESULTS

The results of the mean hourly measurements of the soil sample at the different depth points for the ten PVC tubes over the ten-day period are presented in Table 1.

Table 1: Mean Values of Temperature at Different Depth Points for the 10 PVC Tubes over a 10-Day Period

	DAY 1	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**	**DAY 6**	**DAY 7**	**DAY 8**	**DAY 9**	**DAY 10**
Mean ^{0}C@ 16cm	45.9	36.3	45.9	41.9	44.0	45.1	46.1	36.4	37.7	36.2
Mean ^{0}C@ 18cm	46.6	36.7	45.9	41.1	44.6	45.1	45.7	36.8	37.9	36.1
Mean ^{0}C@ 20cm	44.1	36.3	45.6	41.5	44.1	44.9	45.6	36.3	37.9	35.9

The average bulk density data for each day that measurements were carried out are shown a Table 2.

Table 2: Bulk Density Data

DAY	**AVERAGE BULK DENSITY (kg/m^3)**
1 (23/09/05)	1.30
2 (24/09/05)	1.32
3 (25/09/05)	1.34
4 (26/09/05)	1.36
5 (27/09/05)	1.37
6 (28/09/05)	1.38
7 (29/09/05)	1.40
8 (30/09/05)	1.41
9 (01/10/05)	1.43
10 (02/10/05)	1.45

Presented in Table 3 are the values of the wet soil sample, dry soil sample, moisture content, and percentage moisture content on dry soil basis. A.J. Odofin (personal communication) pointed out that it is universally preferred to express percentage moisture content on "dry soil" rather than "wet soil" basis because the former keeps the denominator constant as the amount of water changes.

Table 3: Values of Wet Soil Sample, Dry Soil Sample, Moisture Content, and Percentage Moisture Content (Dry Soil Basis)

DAY	**WET SAMPLE (g)**	**DRY SAMPLE (g)**	**MOISTURE CONTENT (g)**	**% MOISTURE CONTENT**
1	149	126	23	18
2	175	160	15	9
3	170	155	25	16
4	150	127	23	18
5	190	175	15	9
6	190	174	16	9
7	158	140	18	13
8	175	161	14	9
9	175	160	15	9
10	175	159	16	10

5.0 DISCUSSION

The mean daily temperatures at the different thermometer depth points of the PVC tubes containing the soil sample are comparatively high on Days 1, 3, 4, 5, 6, and 7 and comparatively low on Days 2, 8, 9, and 10. The values of the hourly readings of each of the three thermometers at the 16cm, 18cm, and 20cm depth points did not differ appreciably from one another. From Table 2, it is seen that the bulk density increased from a low of 1.30kgm^{-3} on the first day of measurement to a high of 1.45kgm^{-3} on the tenth day of measurement. This was the result of progressive daily compaction of the soil sample in the course of the experimental work, easily explained by the daily

wetting of the soil sample. It is seen from Table 3 that the percentage moisture content of the soil sample under investigation was highest (18%) on the first and fourth day and lowest (9%) on the second, fifth, sixth, eight, and ninth day.

5.1 Temperature versus Moisture Content Analysis: After completion of the data collection exercise, the average values of temperature were tabulated against the corresponding percentage moisture content, Table 4. At this juncture, the null and alternative hypotheses are generated to test for statistically significant differences amongst the mean temperature values and the relationship between the mean temperature and the moisture content values, viz:

Case 1: H_0: There is no statistically significant difference amongst the various mean temperature values

H_1: There is statistically significant difference amongst the various mean temperature values

Case 2: H_0: There is no statistically significant relationship between the mean temperature and the moisture content values

H_1: There is statistically significant relationship between the mean temperature and the moisture content values

Table 4: Mean Temperature versus Percentage Moisture Content

	DAY 1	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**	**DAY 6**	**DAY 7**	**DAY 8**	**DAY 9**	**DAY 10**
Mean ^{0}C@ 16cm	45.9	36.3	45.9	41.9	44.0	45.1	46.1	36.4	37.7	36.2
%MC@ 16cm	18	9	16	18	9	9	13	9	9	10
Mean ^{0}C@ 18cm	46.6	36.7	45.9	41.1	44.6	45.1	45.7	36.8	37.9	36.1
%MC@ 18CM	18	9	16	18	9	9	13	9	9	10
Mean ^{0}C@ 20cm	44.1	36.3	45.6	41.5	44.1	44.9	45.6	36.3	37.9	35.9
%MC@ 20CM	18	9	16	18	9	9	13	9	9	10

5.1.1 The Chi-Square (χ^2) Test Analysis: The chi-square, χ^2, goodness-of-fit test is now applied to Table 1 in order to determine if there is a statistically significant difference in the mean temperature values at the different thermometer points for the ten days in which data were collected. Table 1 is reproduced as Table 5, seen below.

Table 5: Mean Temperature Values

	DAY 1	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**	**DAY 6**	**DAY 7**	**DAY 8**	**DAY 9**	**DAY 10**	**Total**
Mean ^{0}C@ 16cm	45.90 **(45.62)**	36.30 **(36.50)**	45.90 **(45.88)**	41.90 **(41.58)**	44.00 **(44.32)**	45.10 **(45.12)**	46.10 **(45.88)**	36.40 **(36.57)**	37.70 **(37.90)**	36.20 **(36.13)**	**415.5**
Mean ^{0}C@ 18cm	46.60 **(45.73)**	36.70 **(36.59)**	45.90 **(46.00)**	41.10 **(41.68)**	44.60 **(44.42)**	45.10 **(45.23)**	45.70 **(46.00)**	36.80 **(36.66)**	37.90 **(37.99)**	36.10 **(36.22)**	**416.5**
Mean ^{0}C@ 20cm	44.10 **(45.26)**	36.30 **(36.21)**	45.60 **(45.52)**	41.50 **(41.26)**	44.10 **(43.96)**	44.90 **(44.76)**	45.60 **(45.52)**	36.30 **(36.27)**	37.90 **(37.60)**	35.90 **(35.85)**	**412.2**
Total	**136.6**	**109.3**	**137.4**	**124.5**	**132.7**	**135.1**	**137.4**	**109.5**	**113.5**	**108.2**	**1244.2**

The figures enclosed in parenthesis in Table 5 are the expected values (E_v) and these are calculated by the use of the relation expressed as

$$E_v = (R_t x C_t)/GT \quad (2)$$

where R_t = row total, C_t = column total and GT = grand total. As a matter of illustration, the figure (i.e. E_v) for the first cell having a value of 45.62 was determined as follows:

$$E_v = \frac{415.5x136.6}{1244.2} = 45.62 \quad (3)$$

The functional expression for the chi-square (χ^2)goodness-of-fit given as

$$\chi^2 = \Sigma \frac{(O_v - E_v)^2}{E_v} \quad (4)$$

was used to determine χ^2. Note that in Eq.4, O_v = observed value and E_v = expected value, as pointed out earlier:

$$\chi^2 = \frac{(45.9-45.62)^2}{45.62} + \frac{(36.3-36.50)^2}{36.5} + \frac{(45.9-45.88)^2}{45.88} + \frac{(41.9-41.58)^2}{41.58}$$

$$+ \frac{(44.0-44.32)^2}{44.32} + \frac{(45.10-45.12)^2}{45.12} + \frac{(46.1-45.88)^2}{45.88} + \frac{(36.4-36.57)^2}{36.57}$$

$$+ \frac{(37.7-37.9)^2}{37.9} + \frac{(36.2-36.13)^2}{36.13} + \frac{(46.6-45.73)^2}{45.73} + \frac{(36.7-36.59)^2}{36.59}$$

$$+ \frac{(45.9-46.0)^2}{46} + \frac{(41.1-41.68)^2}{41.68} + \frac{(44.6-44.42)^2}{44.42} + \frac{(45.1-45.23)^2}{45.23} + \frac{(45.7-46.00)^2}{46.00}$$

$$+ \frac{(36.8-36.66)^2}{36.66} + \frac{(37.9-37.99)^2}{37.99} + \frac{(36.1-36.22)^2}{36.22} + \frac{(44.1-45.26)^2}{45.26} + \frac{(36.3-36.21)^2}{36.21}$$

$$+ \frac{(45.6-45.52)^2}{45.52} + \frac{(41.5-41.26)^2}{41.26} + \frac{(44.1-43.96)^2}{43.96} + \frac{(44.9-44.76)^2}{44.76} + \frac{(45.6-45.52)^2}{45.52}$$

$$+ \frac{(36.3-36.27)^2}{36.27} + \frac{(37.9-37.6)^2}{37.6} + \frac{(35.9-35.85)^2}{35.85}$$

$$= 0.0017 + 0.0011 + 0.0000087 + 0.0025 + 0.0023 + 0.0000089 + 0.0011 + 0.00079 + 0.0011 + 0.00014 + 0.017$$

$$+ 0.00033 + 0.00022 + 0.0081 + 0.00073 + 0.00037 + 0.0020 + 0.00053 + 0.00021 + 0.0004 + 0.03 + 0.00022$$
$$+ 0.00014$$

$$+ 0.0014 + 0.00045 + 0.00044 + 0.00014 + 0.000025 + 0.0024 + 0.000070$$

$$= 0.076$$

$$\therefore x^2 = 0.076 \qquad (5)$$

The rejection level, **α**, is set at 0.01 $(i.e. \alpha = 0.01)$ and because of the test-statistic that is invoked (i.e. chi-square) the degree of freedom, **df**, is determined from the relation

$$df = (r-1)(c-1)$$

where r = number of rows and c = number of columns

$$\therefore df = (3-1)(10-1) = 18 \qquad (6)$$

5.1.2 Determination of the Critical χ^2 Value: The critical χ^2 value was determined from standard statistical table to be 7.015.

5.1.3 The Spearman Rank Correlation (r_s) Test Analysis: The Spearman rank correlation is now applied to Table 4 in order to determine if there is any association or correlation between the various mean temperature values at the different thermometer points and the moisture content values; in essence, this is to see if such a relationship is statistically significant. Table 4 is reproduced as Table 6 with the temperature values calculated to be the average at the 16 cm, 18 cm, and 20cm depth marks.

Table 6: Mean Daily Temperature Values at various Depths versus Percentage Moisture Content

Mean daily temp (^{0}C)	**%Moisture content**	**r_1(temp)**	**r_2(%MC)**	**d**	**d^2**
45.5	18	3	1.5	1.5	2.25
36.4	9	9	8	1	1.00
45.8	16	1.5	3	-1.5	2.25
41.5	18	6	1.5	4.5	20.25
44.2	9	5	8	-3	9.00
45.0	9	4	8	-4	16.00
45.8	13	1.5	4	-2.5	6.25
36.5	9	8	8	0	0.00
37.8	9	7	8	-1	1.00
36.1	10	10	5	5	25.00

In Table 6, r_1 and r_2 are the order of ranking of the temperature and moisture content values. The rejection level, **α**, is set at $0.01\left(i.e.\alpha = 0.01\right)$and because of the test statistic that is invoked (i.e. Spearman rank correlation) the degree of freedom, **df**, is determined from the relation expressed as

$df = \left(n-2\right)$, and when n = number of variables

$$df = 10-2 = 8 \tag{7}$$

Now, recall that the formula for the Spearman rank correlation statistic is

$$r_S = 1 - \frac{6\Sigma d^2}{n^3 - n} \tag{8}$$

From Table 6, it follows that

$$r_S = 1 - \frac{6x83}{1000 - 10}$$

$$= 1 - \frac{498}{990}$$

$$= 1 - 0.50$$

$$= 0.50$$

$$\therefore r_S = 0.50 \quad (9)$$

To test for significance, substitute r_s into the relation given as

$$t = r_S \sqrt{\frac{n-2}{1-r_S^2}} \quad (10)$$

It follows therefore that

$$t = 0.50\sqrt{\frac{8}{1-0.25}}$$

$$= 0.50x3.2660$$

$$= 1.63$$

$$\therefore t = 1.63 \quad (11)$$

5.1.4 Determination of Critical t-Value: The critical t value was determined from standard statistical table to be 0.794.

5.2 Temperature versus Bulk Density Analysis: The values of the average daily temperature values at the various thermometer points and the daily bulk density values are presented in the Table 7. At this juncture, the null and alternative hypotheses are generated to test for statistically significant relationship between the mean temperature and the bulk density values, viz:

Case 3: H_0: There is no statistically significant relationship between the mean temperature and the bulk density values

H_1: There is statistically significant relationship between the mean temperature and the bulk density values

Table 7: Mean Daily Temperature versus Bulk Density

	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**	**Day 9**	**Day 10**
Mean ^oC @ 16cm	45.9	36.3	45.9	41.9	44.0	45.1	46.1	36.4	37.7	36.2
BD (kgm^{-3}) @ 16cm	1.30	1.32	1.34	1.36	1.37	1.38	1.40	1.41	1.43	1.45
Mean ^oC @ 18cm	46.6	36.7	45.9	41.1	44.6	45.1	45.7	36.8	37.9	36.1
BD (kgm^{-3}) @ 18cm	1.30	1.32	1.34	1.36	1.37	1.38	1.40	1.41	1.43	1.45
Mean ^oC @ 20cm	44.1	36.3	45.6	41.5	44.1	44.9	45.6	36.3	37.9	35.9
BD (kgm^{-3}) @20cm	1.30	1.32	1.34	1.36	1.37	1.38	1.40	1.41	1.43	1.45

5.2.1 The Spearman Rank Correlation (r_s) Test Analysis: The Spearman rank correlation is now applied to Table 7 in order to determine if there is any association or correlation between various daily temperature values and moisture content values at the different thermometer points.

In essence, this is to see if such a relationship is statistically significant. Table 7 is represented as Table 8 with the temperature values calculated to be the average at the 16cm, 18cm, and 20cm depth marks.

Table 8: Mean Daily Temperature Values at Depth versus Bulk Density

Mean Daily Temp(°C)	**Bulk density**	**r_1 (temp)**	**r_2 (BD)**	**d**	**d^2**
45.5	1.30	3	10	-7	49.00
36.4	1.32	9	9	0	0.00
45.8	1.34	1.5	8	-6.5	42.25
41.5	1.36	6	7	-1	1.00
44.2	1.37	5	6	-1	1.00
45.0	1.38	4	5	-1	1.00
45.8	1.40	1.5	4	-2.5	6.25
36.5	1.41	8	3	5	25.00
37.8	1.43	7	2	5	25.00
36.1	1.45	10	1	9	81.00

In Table 8, r_1 and r_2 are the order of ranking of the temperature and bulk density values. The rejection level, **α**, is set at 0.01 (i.e. $\alpha = 0.01$) and the degree of freedom, **df**, is determined from the relationship of Eq.7, viz:

$$df = (n-2) = 10 - 2 = 8 \qquad (12)$$

Furthermore, arising from Eq. 8 and by Table 8, we have

$$r_S = 1 - \frac{6\Sigma d^2}{n^3 - n}$$

$$= 1\text{-}\frac{6x231.5}{1000-10}$$

$$= 1-\frac{1389}{990}$$

$$= 1-1.403$$

$$= -0.403$$

$$\therefore r_S = -0.403 \quad (13)$$

To test for significance, substitute r_s into the relation by given by Eq. 10, i.e.

$$t = r_S\sqrt{\frac{n-2}{1-r_S^2}}$$

It follows therefore that

$$t = -0.403\sqrt{\frac{8}{1-0.162}} = -0.403x3.09 = -1.25 \quad (14)$$

5.2.2 Determination of Critical t-Value: The critical t value was determined from standard statistical table to be 0.644.

6.0 CONCLUSION

The calculated χ^2 value is seen to be less than the critical value (Case 1), thus the null hypothesis is accepted and we conclude that there is no statistically significant difference amongst the various mean temperature values at the different thermometer points. The critical t-values for Cases 2 and 3 are less that their various calculated t-values (note that it is the absolute t-value that is important in Case 3), therefore we reject the null hypotheses and conclude that (i) there is a statistically significant relationship between the mean temperature and the moisture content values and (ii) there is a statistically significant relationship between the mean temperature and the bulk density values.

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