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Determination of Soil Compaction Levels by Agricultural Machinery in Cultivated Fields Using Dynamic Cone Penetrometer

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Abstract: The increasing soil degradation due to soil compaction may be linked to the increase in weight of agricultural machinery, in the more use of machinery even under unfavourable soil conditions and to poor crop rotation. The objective of the research was to assess the levels of soil compaction in cultivated fields. The research experiment was done in Elfam farm in Moiben Sub County, Uasin Gishu County, Kenya. The soils type was classified as Ferralsols with sandy loam texture. A four wheeled 70 KN tractor was used in the experiments. A multiple linear regression was used to describe the relationships of load, depth and number of passes for penetration resistance. The experiment was conducted at three levels of normal loads of 26 KN, 30 KN and 34 KN and at four levels of number of passes 1, 5, 10 and 15 all with three replications. The penetration resistance were determined at varying levels of loading and number of passes using Dynamic cone penetrometer. The data was analysed using statistical software for analysis of variance (ANOVA) at 95% confidence level and $p < 0.05$. From the results highest penetration resistance was found to be 52.50 J/cm at 30 KN and a depth below 45cm. The lowest penetration resistance obtained was 9.52 J/cm at 26 KN on the top soil layer. During the test period the moisture content average was 25%. The penetration resistance increased with loading, number of passes and depth. The increased loading and number of passes was particularly found to affect the soil layer above 45cm. From the study it was found that the effect loading and number of passes a have significant impact on penetration resistance. The coefficient of determination (R^2) for penetration resistance was found to be 0.8674. The relative compaction from the test results indicate that the soil was 95.5% compacted.

KEYWORDS: NUMBER OF PASSES, LOADING, TEXTURE, SOIL SAMPLING, SOIL DEPTH

I. INTRODUCTION

Soil compaction is recognized as one of the major threat to soil quality. There have been efforts to ameliorate compacted subsoil by mechanical deep-loosening but it is very expensive and often fails. The increasing soil degradation due to soil compaction may be linked to the increase in weight of agricultural machinery [7], in the more intense use of machinery even under unfavourable soil conditions and in addition to poor crop rotation. From an agronomic point of view, soil compaction leads to increased root growth and plant development resulting to a reduction in crop yield [5]. Soil compaction also depends on the type of soil, texture, topography and moisture [1]. Subsoil compaction may persist for a very long time and is hence a threat to the long-term productivity of the soil [4].The increased energy requirement also negatively influences the farmer’s budget: the costs for fuel are high compared with the income from yield, and therefore, it is very important to note that the costs for tillage must be minimized in order to optimize the profit. The amount of energy consumption in tillage (especially in primary tillage) is quite high compared with other farming operations. It is contributing to the persistence of food insecurity due to reduced yields per unit area. Most large scale farmers use heavy machinery and equipment. The manner in which machinery are operated in the fields is haphazard and the operations go beyond the onset of the rainy season. Mechanization of field operations is developed with a full focus on economic profitability. As the hired contractors carry out the various farm operations there is no attention of preventing damage to the soil quality as the contractors are focused on output in terms of hectares ploughed rather than the soil's quality as a growing medium for crop [1].

It is also believed that the risk of undesirable changes in soil structure can be minimized by limiting the mechanically-applied stress to below a threshold stress [8], termed the pre-compression stress. While the concept of pre-compression stress as a threshold between reversible and irreversible strain [6] is widely used, it has been scarcely tested in combination with wheeling experiments in the field. The impact of agricultural machinery on soil properties may be simulated by means of soil compaction models, which are an important tool for developing strategies for prevention of soil compaction.

Soil compaction of the agricultural soil is a global concern to engineers, soil scientists and farmers due to use of large and heavy farm vehicles. It is for this reason that Elfam farm was chosen for experimentation because it is fully mechanized with heavy machinery. It is a real threat to intensification of crop production due to adverse effects associated with it. There is a decrease in crop yield and increase in management costs in areas where soil compaction is prevalent. It also has a negative effect on the environment for example soil erosion, leaching of nutrients, pollution of water bodies and greenhouse gases production.

It has been accelerated by the use of large and heavy machinery and equipment under unfavourable soil conditions. The farming community is solely driven by profitability and without any thought of preserving the soil for tomorrow. Farming community also believed that sub-soiling once in a while will be able to address the issue once their unit production has gone down eroding their profit margins. There is also another school of thought that as long as you are not using a disc or a mouldboard plough no soil compaction will occur, as such they have resorted to using spring-tined chisel plough mostly which require a lot of power [2]. Soil compaction which is a physical form of soil degradation is a subject that is attracting increasing concern worldwide. Not much has been done in Kenya to study, document and make recommendations on the impact of soil compaction due to the use of heavy farm machinery despite being one of the threats soil degradation. This research study was then undertaken to ascertain the extent of soil compactions in cultivated sandy loam soils.

II. MATERIALS AND METHODS

A. Study Area

There are several large scale farms in Moiben division with fully mechanized wheat and maize production. Elfam is one of the several large scale farms in the division with 1012 ha of land. Elfam farm is in Moiben sub County of Uasin Gishu County. It lies to the North East of Eldoret town. It is about 20 km from the Eldoret town along the Eldoret – Iten road. The farm office has the coordinates 0°35'38.5"N and 35°22'15.7"E and the experimental plot has the coordinates 0°35'26.8"N and 35°22'52.8"E. The altitude is 2200 m above sea level. The prevailing rainfall ranges between 900-1100 mm per annum and the soils type is classified as Ferralsols with sandy loam texture [6].The arable land is 607 hectares of which the area under maize is 364 hectares while the remaining is used for wheat growing, barley and *Boma Rhodes* grass for dairy animals. The farm operations are fully mechanized from land preparation to harvesting. The crop production is mainly mechanized and machinery sizes vary from 45 hp to 180 hp. The combine harvesters are large with grain tank capacity of up to 6 tons with a choice of wheat or corn harvesting heads. [3]

B. Experimental plots layout

The experimental plot was divided into three equal sections L1, L2 and L3 each measuring 400 m x 16 m. Each plot was further divided into four subplots each measuring 100 m x 16 m.

C. Determination of the effects of load and passes on Penetration resistance

Dynamic cone penetrometer tests (ASTM D3441) were carried out in all the plots, for every loading, number of passes and for all the selected depths. The reading on the scale rule attached to the Dynamic Cone penetrometer (DCP) was recorded for every drop of the hammer or blow by the hammer (Figure 1 and 2). The different parts of the DCP are summarized by figure 1. It consists of a weight weighing 8 kg, a round smooth steel rod to guide the hammer and attached to the anvil. The 60° replaceable cone tip attached to a 16 mm smooth round steel rod 1m long. A steel rule attached to the anvil and a guide attached to the round steel rod for measuring the depth of penetration in mm. The effective drop height of the weight is 575 mm

D. Dynamic cone penetrometer

The DCP was placed at the centre of the tyre mark and held vertically. The initial reading on the steel scale rule was recorded once

Volume 4 Issue VII, July 2016
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the hammer rested on the anvil. The weight was raised vertically through the effective height of 575 mm and released to freely fall (Figure 2). The reading on the scale rule was recorded for every blow of the hammer until the cone was at least 65 cm to 70 cm below the ground level. The process was replicated three times randomly for every number of passes and loading.

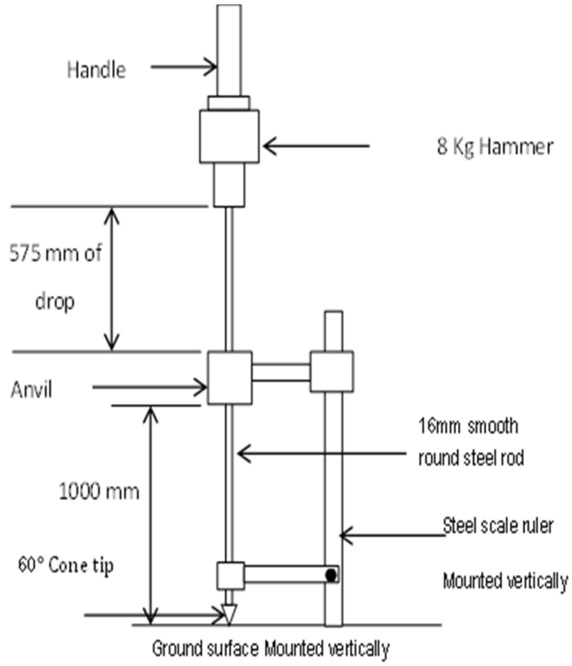

Figure 1: Dynamic cone penetrometer diagram
(Source: Author. 2015)

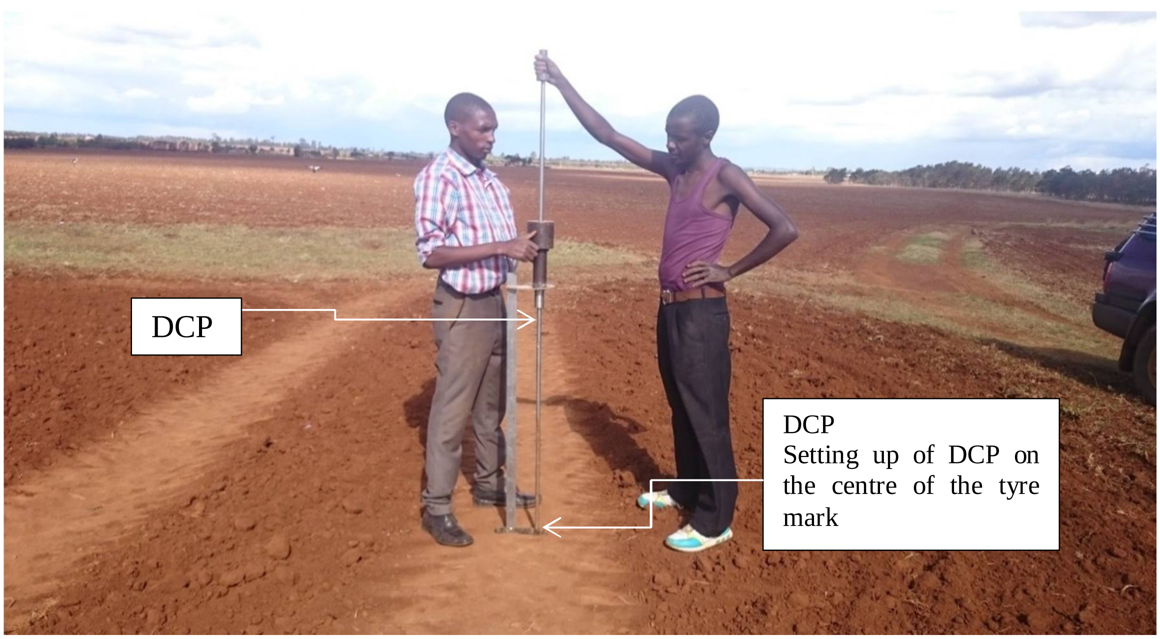

Figure 2: DCP measurement on the centre of the tyre mark

Volume 4 Issue VII, July 2016
ISSN: 2321-9653
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For every fall of the 8 kg hammer the energy released to move the cone into the soil is given by:-

$$\text{Kinetic Energy} = \text{Potential Energy} \qquad \text{Eqn (2.0)}$$

$$\frac{1}{2}mv^2 = mgh \qquad \text{Eqn (2.1)}$$

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 0.575} = 3.39 \text{ m/s}$$

$$\text{Kinetic energy} = \frac{1}{2}mv^2 = \frac{1}{2} \times 8 \times 3.391^2 = 46 \text{ Joules (J)}$$

The Penetration resistance is therefore calculated using the following equation

$$\text{Penetration resistance(PR)} = \left\{\frac{\text{number of blows of the hammer(N)} \times 46}{\text{Depth moved(d) in cm}}\right\} \text{ J/cm}$$

$$\text{Penetration resistance(PR)} = \frac{N \times 46}{d \text{ in cm}} \text{ J/cm} \qquad \text{Eqn (2.2)}$$

The penetration resistance results were calculated using equation (2.2).

III. RESULTS AND DISCUSSION

A. *Effects of loading and number of passes on penetration resistance*

B. *The 0-15 cm soil layer with varying loading level*

The top soil layer which is normally affected by all farm operation(Figure 3) is least affected and it has the initial penetration resistance of 9.52 J/cm for one pass, 16.24 J/cm for 15 number of passes an increase of 70.6 % for a loading level of 26 kN. The penetration resistance increases with increase in loading. It also increases with the increase in the number of passes. The 22.08 J/cm is the highest penetration resistance for the highest loading and number of passes for this layer.

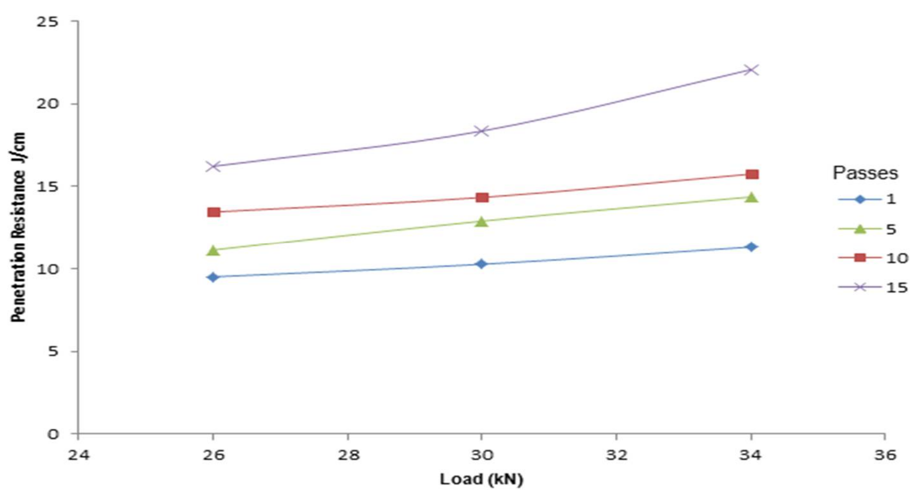

Figure 3: Effect of loading on PR for selected number of passes for 0-15 cm soil layer

C. *Effects of the Number of Passes on Penetration Resistance for selected depths and various loading.*

The effects of the number of passes as depicted by figure 21 clearly show that the highest number of passes has a higher impact on the penetration resistance as opposed to the single pass. For a single pass the Penetration resistance on the 45 –

Volume 4 Issue VII, July 2016
ISSN: 2321-9653

60 cm layer was found to be 15.86 J/cm and 42.41 J/cm for 15 passes. The highest number of passes affects all the selected soil layers. This means that as you increase the number of passes the impact on the soil goes deeper into the soil. The same trend applies to all the other loading levels of 30 kN and 34 kN (Figure 4 and 5)

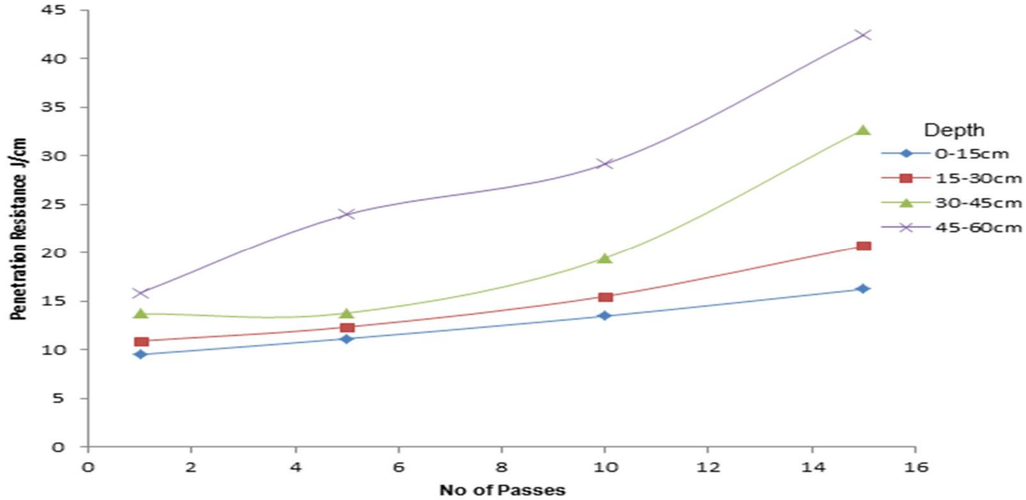

Figure 4: Effects of the Number of passes on PR for selected depth range and a loading of 26 kN

D. Effect of number of passes on PR on 0-15 cm soil layer with selected load

The number of passes and selected loads show increase in penetration resistance with increase in the number of passes. There is also vertical increase in penetration resistance due to increase in loading (Figure 5). For a single pass at a loading of 26 kN the PR is 9.52 J/cm and the same at a loading of 34 kN the PR is 11.33 kN which is an increase of 19%. The penetration resistance for 15 passes at 26 kN is 16.24 J/cm and for 15 passes at 34 kN is 22.08 J/cm reflecting an increase of 36%. Considering the change in in terms of number of passes for one pass and 15 passes at 26 kN the increase is 70.6 %, same for a loading level of 30 kN is 79 % and for 34 kN is 95 %. Similar trends can be seen for all the other layers but at different percentage increase.

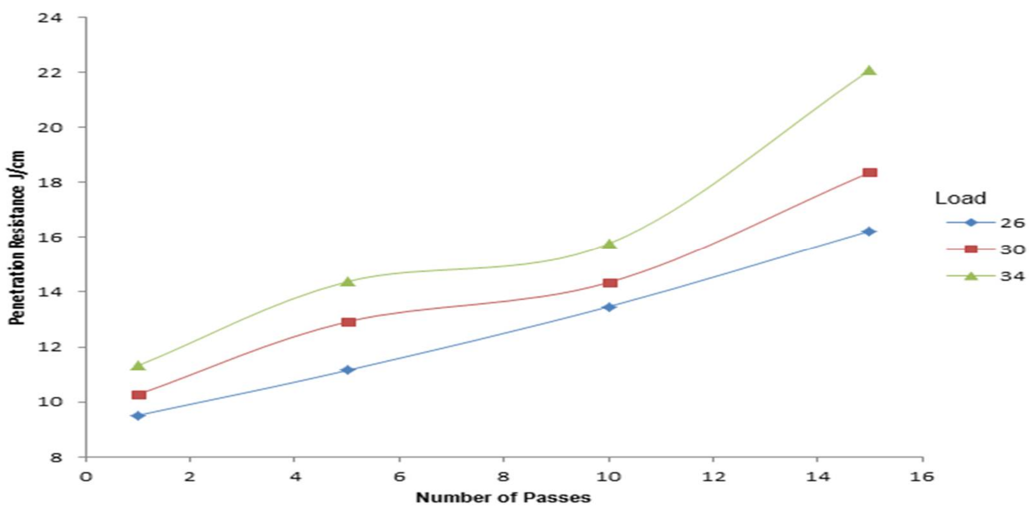

Figure 5: Effect of number of passes on PR for selected loads for 0-15cm soil layer

E. Analysis of variance for Penetration Resistance

The multiple regression analysis of variance for penetration resistance was done using stepwise method and at 95% confidence level and the P-value of $\alpha = 0.05$. The results are displayed on the ANOVA table (Table 1).The evaluated results shows that the load,

Volume 4 Issue VII, July 2016
ISSN: 2321-9653

depth and number of passes are all significant at 95% confidence level. The regression equation coefficient of determination (R^2) was 0.8140.

Table 1: Analysis of Variance (ANOVA) for penetration resistance

Source	DF	SS	MS	F	P
D	3	3218.84	1072.95	40.05*	0.000
L	2	598.59	299.30	11.17*	0.000
P	3	755.07	251.69	9.40**	0.000
Error	39	1044.72	26.79		
Total	47	5617.23			

*Significant at 5%
**Significant at 1%
Coefficient of determination $R^2 = 0.8140$

F. Penetration resistance analysis regression equation.

The penetration resistance regression equation was developed based on the loading, number of passes and depth. The proposed regression equation for the prediction of penetration resistance at any given depth, load and number of passes is given by Equation 3.0

$$PR = 1.079\ L + 0.4798\ D + 0.733\ P - 29.16 \qquad \text{Eqn (3.0)}$$

Where PR - Penetration resistance (J/cm), D - Depth (Cm), L - Load (kN) and P – Passes.

The proposed regression equation 3.0 was used to predict the penetration resistance compared graphically with measured results Figure 6, the coefficient of determination (R^2) when the intercept is taken to be the origin (x=0, y=0) is 0.7389 while in the case where there is an intercept the coefficient of determination R^2 is 0.8674. The fitted line is a second degree polynomial correlation with the highest coefficient of determination.

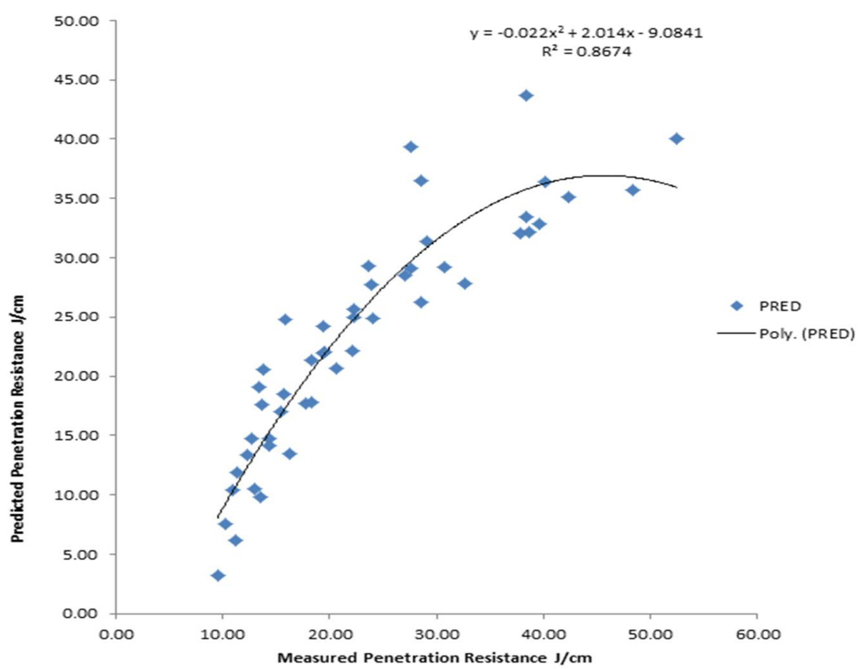

Figure 6: Measured Penetration Resistance against predicted Penetration resistance graph

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Using Principal component analysis (PCA) method it was established that in equation 3.0 the final penetration resistance consist of 0.46 proportion of loading, 0.25 proportion numbers of passes and finally 0.25 proportion of depth (Table 2). The results show that the loading has the highest impact on the penetration resistance and contributes 46% to soil compaction while the number of passes and depth contribute 25% each.

Table 2: Principal component analysis for penetration resistance

	L	D	P	PR
Variance	1.84	1.00	1.00	0.16
Proportion	0.46	0.25	0.25	0.04
Cum. Proportion	46.1%	71.1%	96.1%	100.0%

IV. CONCLUSIONS

The maximum dry density (MDD) was 1376 kg/m3.Observed bulk density 1116 to 1513 kg/m3 and the Relative compaction was 81.1% to 110%

A. Loading and the number of passes were found to have a significant impact on penetration resistance.

B. The increase in loading has more effect on the lower layers of the soil than the number of passes.

C. The coefficient of determination (R^2) penetration resistance was found to be 0.8674.

V. ACKNOWLEDGMENT

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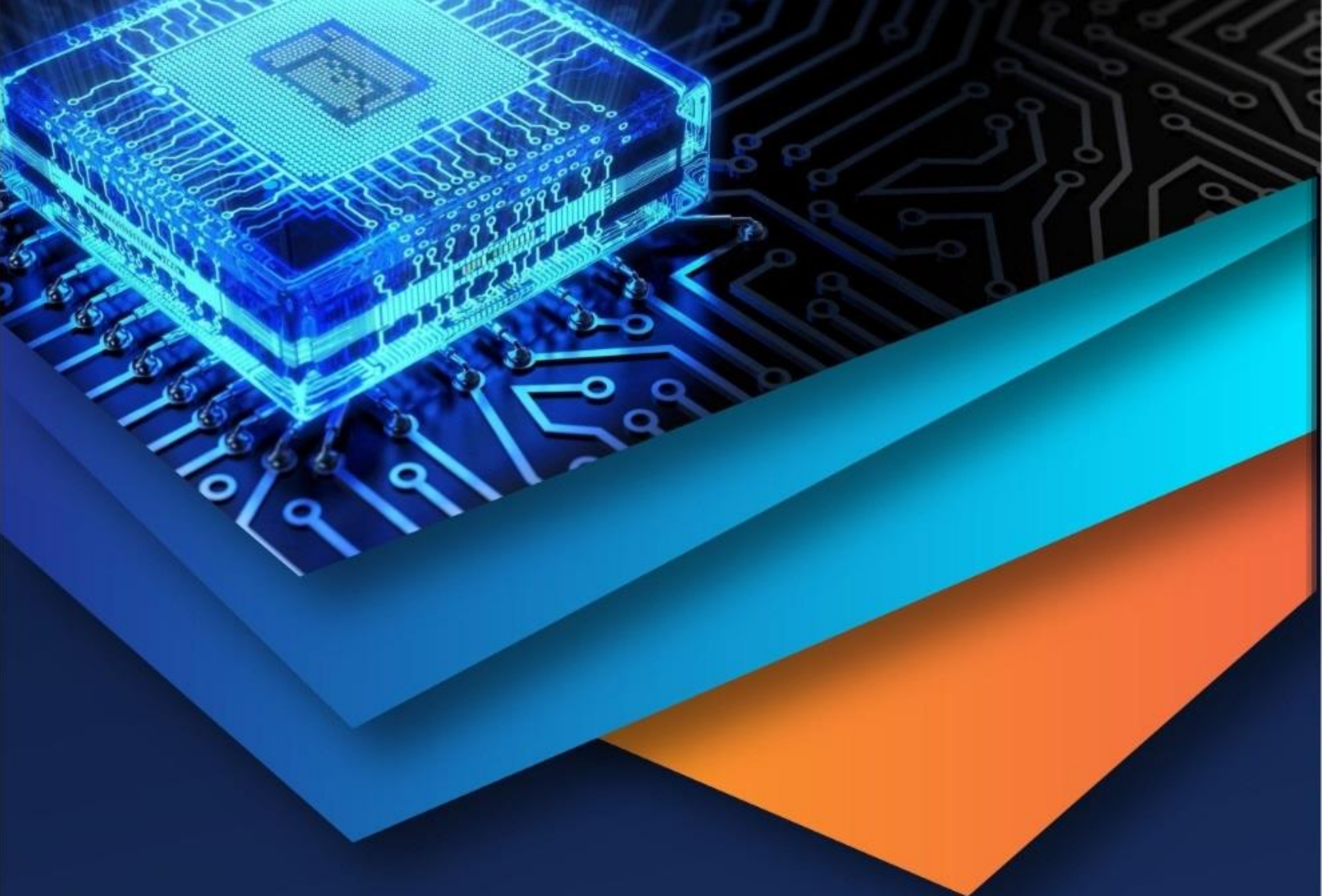

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