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Nitrogen Management Strategies to Improve Growth and Yield of Rice under Irrigated Conditions

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Abstract: An experiment was carried out at the Soil and Irrigation Research Centre, Kpong of the University of Ghana, Legon in 2023 and 2024 to study the influence of nitrogen (N) management strategies on rice growth and yield. The design was a split-split plot design with nitrogen (N) rate (90 and 120 kg ha^{-1}) as the main plot, basal N: topdress N ratio (50%:50%, 40%:60%, and 60%:40%) as a subplot, and mode of basal N application (one time and 2-split) as sub-subplot. There were three replicates and the rice variety Legon Rice 1 (Ex Baika) was used. The N rates of 90 and 120 kg ha^{-1} were not different in grain yield with average grain yields of 5164 and 5295 kg ha^{-1}, respectively. There was no difference in grain yield among the basal: topdress N ratios of 50%:50%, 40%:60%, and 60%:40% with yields of 5269, 5152, and 5266 kg ha^{-1}, respectively. However, applying basal N as 2-split recorded an average yield of 5677 kg ha^{-1} and this was significantly higher than the one-time application of basal N which had a mean grain yield of 4781 kg ha^{-1}, representing a yield difference of 15.7 %. For environmental and economic reasons, irrigated rice farmers on the Vertisols of the Accra Plains can adopt the option of applying N at 90 kg N ha^{-1} with the basal N applied as two splits using a basal: topdress N ratio of 60%:40% or 50%:50% since this has the potential to increase yield.

Keywords: nitrogen management, rice yield, split-split plot design, basal nitrogen application.

I. INTRODUCTION

Nitrogen (N) plays a very important role in the nutrition and productivity of crops and deficiency of N limits crop growth and yield. For rice, the response of varieties to N in rice fields is generally recognized [1]. One way of increasing the productivity of irrigated rice is by effective N management. According to Alagesan and Raja Babu [2], insufficient and inappropriate N fertilizer application may account for two-thirds of the gap between actual and potential yields. For economic and environmental reasons, N fertilizer should be applied at a rate that does not exceed the expected crop N requirement and at the time when the plant needs to reduce the chance for potential losses and to prevent undue nutrient enrichment of the environment [3].

In Ghana, irrigated rice is usually fertilized twice during the life cycle of the plant. Basal N (50 % N) is applied 7-14 days after transplanting or 21-28 days after emergence of direct-seeded rice. The top-dress N (50 % N) is applied at the panicle initiation stage. N fertilizer applied as basal N is mainly used for increasing the number of panicles while N fertilizers top-dressed at mid-season i.e., the fertilizers top-dressed at the panicle initiation and spikelet differentiation stage, are most effective in increasing grain yield because it is usually used to increase the number of differentiated spikelets, prevent differentiated spikelets from degeneration, and increase the percentage of filled grain [4, 5]. Different strategies to improve N nutrition from soil and fertilizers have been investigated. These include proper timing, rate, type and placement of the fertilizer [6].For example, the timing of N application in studies by Merkebu and Techale [7] in Ethiopia did not affect rice grain yield. According to Xue and Yang [8], reducing the early-stage (basal) fertilizer rate and applying more fertilizer (topdress) at mid-season has the potential to improve the N use efficiency (NUE) and grain yield. In a related study, Sun et al. [9] were of the view that a top-dress N ratio of 40 % had a positive effect on yield as it improved the remobilization of nutrients from vegetative plant parts to grains during grain-filling. On the contrary, Wu et al. [10] observed that when the top-dress N ratio exceeded 35% in double-season early rice, the change in leaf colour from green to yellow due to the remobilization of N from leaves was delayed, and this affected grain-filling and yield increase. As a result, rice crop response to N management strategies may be affected by several factors such as rice variety, soil type, water management, N management, climate, etc. Effective N management strategies are, therefore, still needed to enhance rice productivity in existing irrigated rice systems. The present study was therefore conducted to investigate the growth and yield response of rice to various N management strategies.

II. MATERIALS AND METHODS

The experiment was conducted on a Calcic Vertisol [11] at the Soil and Irrigation Research Centre, Kpong (6^0 9' N, 0^0 4' E) of the University of Ghana, Legon in the minor season (September-December) of 2023 and major season (April-July) of 2024. The area experiences a bi-modal rainfall pattern (major and minor seasons), with a mean annual precipitation of about 1135 mm. The major season begins from March to July and the minor season from September to November. The mean air temperature is 27.2 ^oC with mean maximum and minimum air temperatures of 33.3 and 22.1 ^oC, respectively. Soil samples were collected before the start of the experiment for analysis. Soil pH was determined in water at a ratio of 1:1, organic carbon by the dichromate-acid oxidation method, total N by the Kjeldahl digestion and distillation procedure, available P by Olsen, cation exchange capacity by the ammonium acetate method at pH 7, and bulk density by the core method. The design was a split-split plot design with N (N) rate (90 and 120 kg ha^{-1}) as the main plot, basal N: topdress N ratio (50%:50%, 40%:60%, and 60%:40%) as subplot and mode of basal N application (one time and 2-split) as sub-subplot. There were three replicates and the rice variety Legon Rice 1 (Ex Baika) was used. After field preparation which involved puddling and leveling, 18-day-old seedlings were transplanted with 2 seedlings per hill. Seedlings were transplanted in each plot (3 m × 4 m) at a spacing of 20 cm within rows and 20 cm between rows, giving a total plant population of 25 hills m^{-2}. Plots were kept free of weeds and water was controlled as required. Phosphorus (45 kg ha^{-1} P_2O_5 as triple superphosphate) and potassium (45 kg ha^{-1} K_2O as potassium chloride) were applied at transplanting to all plots. Urea was used as the source of N and the appropriate amount of basal N was applied Basal N was applied 10 days after transplanting (one-time application) while for the 2-split basal N application, basal N was split-applied at 10 and 17 days after transplanting. Topdressing of N was done at panicle initiation stage. A sample of five hills per plot was collected at the active tillering and booting stage and oven-dried at 80 ^oC for 3 days to estimate dry matter. Days to 50% heading was recorded. At harvest, plants were harvested from 4 m^2 in each plot. Five hills from each plot were randomly selected for measurement of the total number of effective tillers per hill. Twenty random panicles were collected to estimate the total filled grains per panicle and 1000-grain weight. A sample of five hills was taken and threshed and the fresh weights of grain and straw were recorded. The samples were oven dried at 80 ^oC for 3 days and the dry weights of straw and grain were obtained. Harvest Index was obtained by dividing the sample grain weight by the total biomass of the sample. The crop growth rate was estimated with Equation 1 below. Analysis of variance was conducted using the procedures of SAS [12].

$$CGR\ (gm^{-2}day^{-1}) = \frac{(B_2 - B_1)}{(T_2 - T_1)} \quad \text{...} \quad (1)$$

where CGR is crop growth rate, B_1 and B_2 are plant dry weight harvested at times T_1 and T_2, respectively.

III. RESULTS

A. *Physical and Chemical Properties of the Soil*

The characteristics of the soil are presented in Table 1 and Table 2. The soil has a pH of 6.6 and an organic carbon content of 0.84%. Total N, available phosphorus, and cation exchange capacity values were 0.12%, 5.75 mg kg^{-1}, and 36.6 $cmol_c$ kg^{-1}, respectively. Bulk density ranged between 1.42 and 1.50 Mg m^{-3}, with a clay content of between 56 and 60.8%. Saturated water varied between 32 and 40 %. Silt content ranged between 2.5 and 2.9%.

Table 1. Chemical properties of the soil at the experimental site at Kpong, Ghana

Property	Value
pH (H_2O)	6.60
Organic carbon (%)	0.84
Total nitrogen (%)	0.12
Available phosphorus (mg kg^{-1})	15.7
CEC ($cmol^c$ kg^{-1})	36.6

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Table 2. Physical properties of the soil at the experimental site at Kpong, Ghana

Soil depth (cm)	Bulk density (Mg m^{-3})	Sand	Silt	Clay	Textural class
		………….	%................		
0-10	1.43	41.1	2.9	56.0	Clay
10-20	1.42	36.7	2.9	60.4	Clay
20-30	1.50	36.7	2.5	60.8	Clay

B. *Dry Matter Accumulation*

Figure 1 illustrates dry matter accumulation as influenced by basal: top dress N ratio across modes of basal N application and N rates over two years. There was little difference in dry matter accumulation among the three basal: top dress N ratio treatments from emergence to maturity. Dry matter accumulation was slow from emergence to active tillering earlier in the season. There was a sharp increase in dry matter accumulation from active tillering to booting and this slowed down from booting to maturity. N rate influenced dry matter production (Figure 2) such that 120 kg N ha^{-1} (120N) recorded slightly higher dry matter accumulation compared with 90 kg N ha^{-1} (90N)

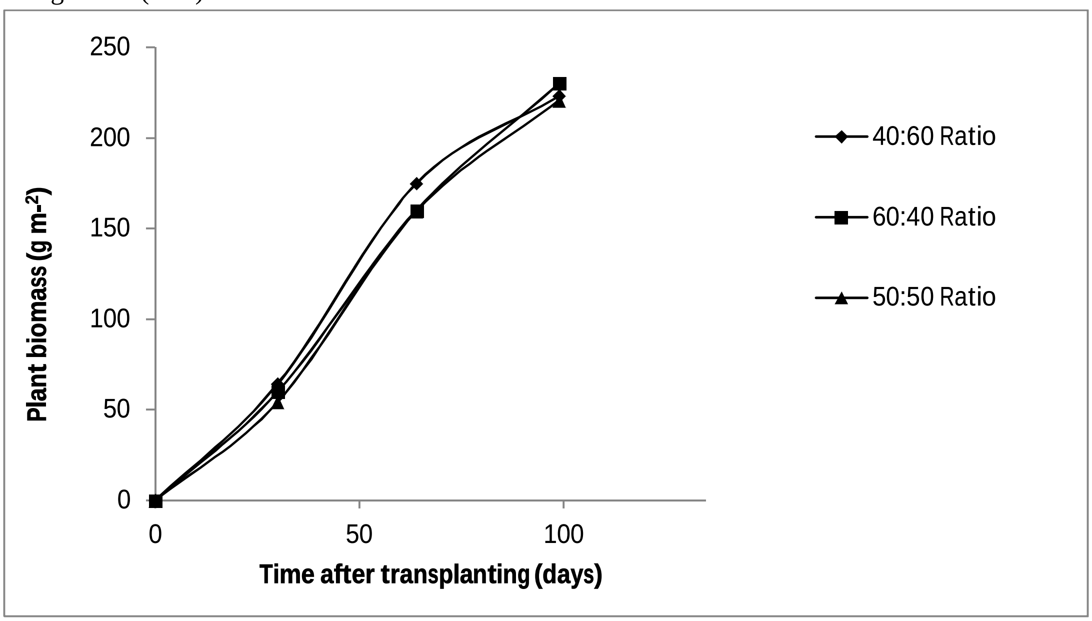

Figure 1. Dry matter production as affected by basal: topdress N ratio over two years

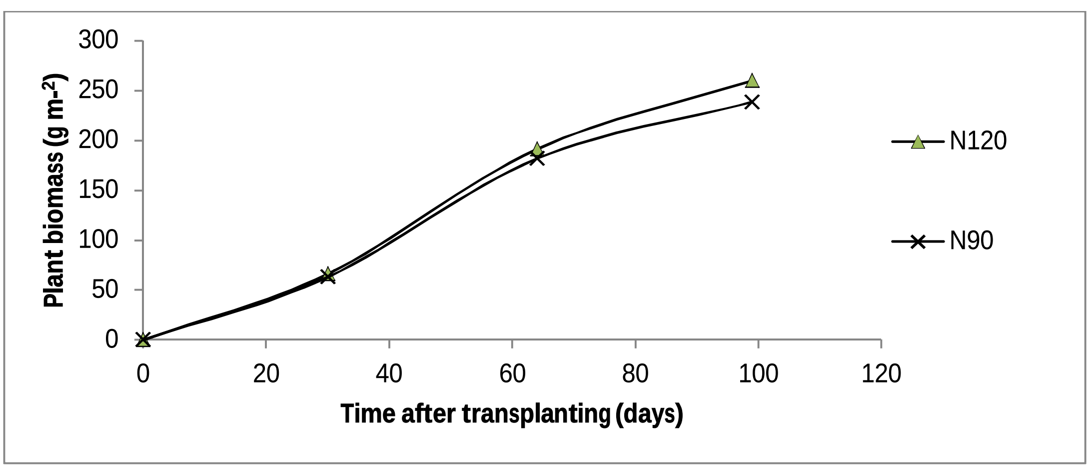

Figure2. Dry matter production as affected by N rate over two years

C. Crop Growth Rate

Crop growth rate (CGR) at different stages of rice varieties as influenced by N rate is shown in Table 3. The crop growth rate was initially slow followed by a sharp rise before eventually declining. The crop growth rate between active tillering and booting was higher compared with the CGR between emergence and booting (EM-BT) and between booting and maturity (BT-MT). Basal N ratio influenced CGR with 50:50 and 60:40 recording significantly higher CGR than 40:60 at 90 kg N ha^{-1}. On the other hand, basal N ratio had no effect on the crop growth rate at the higher N rate of 120 kg N ha^{-1}, though the crop growth rate was generally higher than the CGR at 90 kg N ha^{-1}

Table 3. Crop growth rate (g m^{-2} day^{-1}) of basal N ratio at two N rates over two years

N ratio	EM-AT	AT-Booting	Booting-Harvest
	------------------------ 90 kg N ha^{-1} -----------------------		
50:50	7.2a	14.7a	8.7a
40:60	6.4ab	12.2b	6.2b
60:40	6.9a	15.1a	9.1a
	------------------------ 120 kg N ha^{-1} ----------------		
50:50	6.8a	16.7a	7.7a
40:60	6.5a	15.8a	6.0a
60:40	6.6a	17.3a	7.8a

Means followed by same letters in a column are not significantly different ($p < 0.05$)

D. Yield Components

Tables 4 and 5 show the results of yield components. In general, the N ratio did not affect panicles per square meter under both one-time basal N and 2-split basal N application at both 90 and 120 kg N ha^{-1}. However, panicles per square meter were significantly influenced by mode of basal N application, with 2-split basal recording significantly higher panicles per square meter than one-time basal N application. Panicles per square meter averaged 268 for one-time basal N application and 292 for 2-split basal N application across N ratio and N rate. Mode of basal N application, N rate, and N ratio did not affect the Harvest Index as the differences observed were not significant over the two years. Similarly, the N ratio and mode of basal N application did not affect filled grains per panicle and 1000-grain weight.

Table 4. Panicles per square meter and Harvest Index as affected by N rate, basal: topdress N ratio and mode of basal N application over two years

N Ratio	Panicles per m^2		Harvest index	
	One-time basal application	2-split basal application	One-time basal application	2-split basal application
	-------------------------------------- 90 kg N ha^{-1} -----------------------------			
50:50	230b	298ab	0.443a	0.442a
40:60	275a	270b	0.431a	0.440a
60:40	272a	315a	0.436a	0.438a
	------------------------------------- 120 kg N ha^{-1} -------------------------------			
50:50	285a	287a	0.451a	0.452a
40:60	280a	286a	0.446a	0.443a
60:40	268a	298a	0.441a	0.412a

Means followed by the same letters in a column are not significantly different ($p < 0.05$)

Table 5. Filled grains per panicle and 1000-grain weight as affected by N rate, basal:topdress N ratio and mode of basal N application over two years

N Ratio	Filled grains per panicle		1000-grain weight	
	One-time basal application	2-split basal application	One-time basal application	2-split basal application
	--- 90 kg N ha^{-1} ---			
50:50	104a	103a	24.2a	24.1a
40:60	110a	109a	24.6a	24.6a
60:40	100a	104a	24.5a	25.2a
	--- 120 kg N ha^{-1} ---			
50:50	108a	104a	25.6a	25.3a
40:60	102a	94a	24.7a	24.5a
60:40	102a	102a	24.8a	24.7a

Means followed by the same letters in a column are not significantly different ($p < 0.05$)

E. *Grain and Straw Yield*

Table 6 presents grain and straw yield over the two seasons. Applying basal N as 2-split recorded an average yield of 5677 kg ha^{-1} and this was significantly higher than one one-time application of basal N which had a mean grain yield of 4781 kg ha^{-1}. On the other hand, observed grain yield differences due to N rate and N ratio were not significant. Interaction among the factors was not significant except for the interaction between the mode of basal N application and N rate. Differences observed in straw yield as a result of N rate, N ratio and mode of basal N application were not significant.

Table 6. Grain and straw yield of mode of basal N application as influenced by N ratio at two N rates over two years

N Ratio	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
	One-time basal application	2-split basal application	One-time basal application	2-split basal application
	--- 90 kg N ha^{-1} ---			
50:50	4782a	6012a	5853a	6909a
40:60	4967a	5163b	7634a	7149a
60:40	4990a	5849a	6389a	8088a
	--- 120 kg N ha^{-1} ---			
50:50	4864a	5416a	6934a	7023a
40:60	4662a	5815a	7221a	6239a
60:40	4421a	5804a	5889a	6852a

Means followed by the same letters in a column are not significantly different ($p < 0.05$)

IV. DISCUSSIONS

The lack of any major differences in dry matter production and crop growth rate for the three basal: topdress N ratios is an indication that their effect on dry matter production was similar. This means all three basal: topdress N ratios supplied similar amounts of N during the various stages of the crop [13]. The highest crop growth rate (CGR) which was recorded between the active tillering and the booting stage shows that this stage was the most vigorous growth stage of the rice. Garces-Varon and Restrepo-Diaz [14] in a related study confirmed this stage to be the stage with the most rapid growth rate in rice. The lack of any difference in panicles per m^2, Harvest Index (HI), filled grains per panicle, and 1000-grain weight among the three basal: topdress N ratios is because all three ratios supplied enough and/or similar N amount overall to meet the N requirement of the plants both at the vegetative and reproductive stages [13]. This result disagrees with the findings of Kaushal et al. [15] who observed significant differences in productive tillers per hill due to different ratios of basal: topdress N. The higher N rate, different varieties and different N ratios used in their study may have accounted for the different results.

Harvest index (HI), is a measure of partitioning to plant parts and high HI implies more partitioning to reproductive plant parts. Although higher-yielding cultivars generally tend to have a higher harvest index (HI), a relatively higher HI does not always lead to higher yield [16]. As a result, the similar HI observed for the three N ratios is only an indication that the partitioning ratio to reproductive and vegetative parts was similar [17]. The fact that filled grains per panicle were not influenced by the mode of basal N application, N rate, and N ratio is because filled grains per panicle is a varietal trait, and that the environmental conditions that existed did not have a major influence on it. This result disagrees with Kaushal et al [15] who observed significant differences in filled grains per panicle due to different ratios of basal: topdress N. The higher N rate, different varieties and different N ratios used in their study may have accounted for the different results. Kaushal et al [15] and Ofori et al. [18] observed no difference in 1000-grain weight due to N ratio and N rate and this confirms the results from this study. They concluded that the 1000-grain weight was a varietal trait. and that the environmental conditions that existed did not have a major influence on it. Castro and Siddique Sarker [13] noted that when different proportions of a total level of N were used as basal-topdress N, grain yield and dry matter production did not significantly differ among the different treatments used. This finding by Castro and Siddique Sarker [13] further supports the results of this study. On the contrary, Wu et al [10] observed that, increasing the amount of topdress N increased dry matter and grain yield of rice. The results of Zhang et al [5] were also confirmed by Sun et al. [9]. Chang et al [19] concluded that these observations may be due to the limited number of varieties used in these studies as well as the fertility status of the soils used. For example, Chen et al [20] observed that 80 % of N within a rice crop was derived from soil N when the rice crop was fertilized with fertilizer N at 140 kg ha^{-1}. Xu et al [21] in a related study also reported that the effect of an increased ratio of panicle N (topdress N) on grain yield was related to the basic fertility of the soil. Xu et al [21] concluded from their study that, increasing the ratio of panicle N (topdress N) had no effect on grain yield in high-fertility soils, but could increase the grain yield of rice grown in low-fertility soil. Chang et al [19], using 10 varieties of rice in both low and high-fertility clayey soils concluded that, the effect of a higher ratio of panicle N (topdress N) was dependent on rice variety, meteorological conditions, and soil fertility.

This study revealed that the N rates and basal: topdress N ratio used did not have a different effect on yield components and grain yield. However, the significant effect of 2-split basal N application on grain yield was due to its effect on productive tillers and a number of panicles.

N fertilizer applied as basal N is mainly used for increasing the number of panicles while N fertilizer applied as top-dress at mid-season i.e., the fertilizers top-dressed at the panicle initiation and spikelet differentiation stage, are most effective in increasing grain yield because it is usually used to increase the number of differentiated spikelets, prevent differentiated spikelets from degeneration, and increase the percentage of filled grain [4]. This means that any reduction in the number of panicles due to insufficient or improper N management earlier in the season will ultimately lead to reduced yield regardless of whether the topdress N is adequate or not. According to Wang et al [22], the basal fertilizer is an effective long-term fertilizer and the proportion of total N at full heading was much greater from the basal N than the topdress N, especially in clayey paddy soils. A major reason for the poor N recovery efficiency of higher fertilizer N application at the early growth stages of rice is that the roots of rice are less developed at this stage and so the plants can hardly take up the higher N applied at this stage [23]. This can have negative consequences for the environment due to greater potential losses into the environment. Split application of the basal N is, therefore, more likely to improve N recovery and eventually increase the number of productive tillers and panicles to eventually increase yield while minimizing losses into the environment.

V. CONCLUSION

Results from this study conducted on the heavy black clays (Vertisols) of the Accra Plains showed that using a basal: topdress N ratio of 50%:50%, 40%:60%, and 60%:40% did not differently influence grain yield at N rates of 90 and 120 kg N ha^{-1}. Also, using a N application rate of 90 and 120 kg N ha^{-1} had a similar effect on grain yield. Splitting the basal N into 2 halves such that one half is applied 10 days after transplanting and the second half 17-18 days after transplanting can increase yield. For environmental and economic reasons, irrigated rice farmers on the Vertisols of the Accra Plains can therefore adopt the option of applying N at 90 kg N ha^{-1} using a basal: topdress N ratio of 60%:40% or 50%:50%, with the basal N split into two equal applications since this has the potential to increase yield. It is also worth mentioning that, the irrigated rice environments on the Accra Plains have different soil types ranging from heavy clays to silty clays with varying levels of fertility. There is therefore the need to assess the effect of different N management strategies to optimize yield on the different soils.

VI. ACKNOWLEDGMENTS

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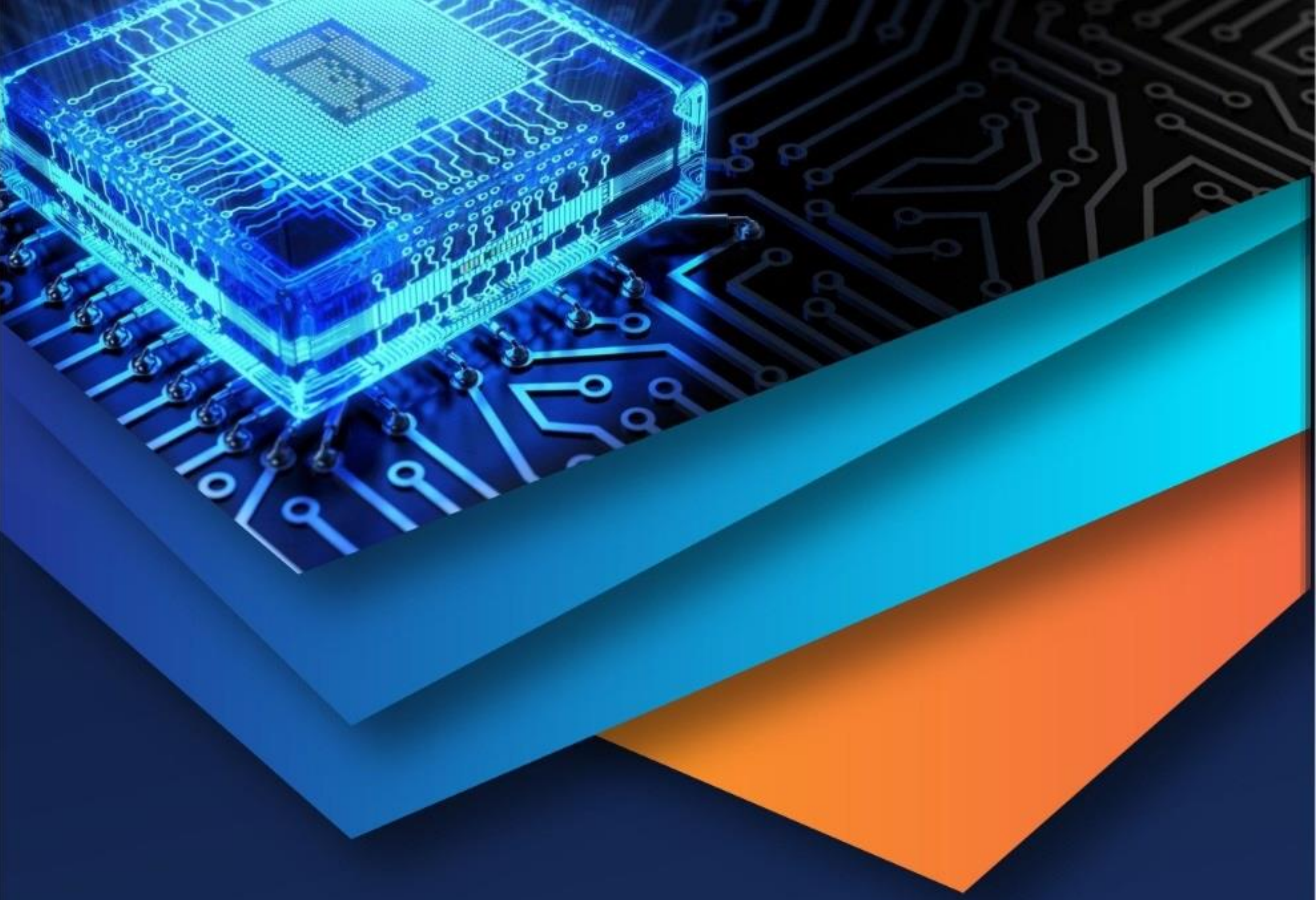

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