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Effect of biochar fortified with urea on soil properties and nutrient uptake of *Amaranthus cruentus* in Calabar, South-eastern Nigeria

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Abstract

A screen – house trial was conducted in the University of Calabar Teaching and Research Farm to assess the impact of biochar fortified with urea fertilizer on soil pH, organic carbon, total nitrogen, available phosphorus, C: N ratio, nutrient uptake and dry matter yield of *Amaranthus cruentus*. Eight treatments comprising of the control (no amendment), sole applied biochar (B) at 20 t/ha, urea alone (U) at 60 kg N/ha, ½ B + ½ U, ¾ B + ¼ U, ¼ B + ¾ U, Full B + ½ U and ½ B + Full U were laid out in a completely randomized design (CRD) with three replications. The experimental soil was loamy sand with a pH of 5.1. Amendments used significantly ($p < 0.05$) increased the soil pH from 5.10 and 5.330 (strongly acidic) obtained before experiment and control, respectively to values ranging from 5.833(moderately acid) to 6.500 (slightly acid). The highest soil pH (6.500), organic carbon (3.060%) and C: N ratio (16.11) were obtained in soil amended with Full B + ½U, the highest total N (0.21 %) was in ¾ B + ¼ Untreated soil while the highest available P (25.96 mg/kg) was in sole biochar. Significant ($p < 0.05$) increases in nutrients uptake by *Amaranthus* were recorded with the highest N and Ca obtained from urea alone treated plants, P and K uptake from full B + ½ U plants while Mg-uptake was not significantly ($p > 0.05$) affected. Dry matter yield of *Amaranthus* was significantly ($p > 0.05$) increased with the highest value (0.96 t/ha) obtained from plants treated with Full B + ½ U (20 t/ha biochar + 30 kg N/ha urea). Therefore, biochar fortification with urea fertilizer is recommended for improved soil properties and enhanced performance of *Amaranthus* in the rainforest *Ultisol* of Calabar.

Keywords: Biochar, nutrient uptake, soil properties.

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1.0. Introduction

Soils in the tropical rainforest of Nigeria are inherently low in fertility and characteristically low in soil organic matter content and cannot sustainably support intensive cultivation due to heavy rainfall which causes erosion and leaching of soil nutrients. Tremendous efforts have been made by scientists to improve and boost the sustainability of crop production in soils of low inherent fertility. Farmers and researchers have employed the use of various fertilizers from both organic and inorganic sources to address these problems (Glaser *et al.,* 2002; Lehmann and Rondon, 2006; Novak *et al.*, 2009; Iren *et al.*, 2014 & 2015, Udoh *et al.*, 2016, Udoh and Iren, 2016). The sole use of inorganic fertilizer to increase yield is useful as a short term solution which demands consistent use on a long-term basis. On the other hand, organic source of fertilizers not only add organic matter to the soil but also contain all the essential nutrients needed by crops (Iren *et al.*, 2015 & 2017). However, the common disadvantages of organic sources of fertilizers are their unavailability in large enough quantity and the low nutrient content of most of the manure. Therefore, complimentary use of organic and inorganic fertilizers has been proved to be a good soil fertility management strategy (Adeniyan and Ojeniyi, 2005; Obasi *et al.,* 2006, Iren *et al.*, 2014& 2016). Organic fertilizers fortified with inorganic materials are formulated to replenish the soil and improve plant fertilization.

Recently, the effort of agricultural and environmental researchers is pointing in the direction of biochar as a veritable technology that could be used to deal with some of these concerns (Ibiremo and Akanbi, 2015; Adeyemi and Idowu, 2017). Biochar is a carbon-rich and porous material that is resistant to decomposition in the natural environment due to its condensed structure (Spokas *et al.*, 2012). Because of its stable organic carbon content, large specific surface area, and negative surface charge (Mukherjee *et al.*, 2011), biochar has been widely recognized as a beneficial soil amendment for its role in improving soil physical (Lehmann, 2007a), chemical (Glaser *et al.*, 2001; Ventura *et al.*, 2013), and biological properties (Glaser *et al.* 2002, Lehmann and Rondon, 2006, Warnock *et al.,* 2007), as well as in enhancing crop productivity (Chan and Xu, 2009; Tian *et al.*, 2018).

Biochar's ability to impact essential properties to the soil, such as raising of soil pH and water holding capacity, attraction of beneficial fungi and microbes, improvement of cation exchange capacity (CEC), high carbon sequestration ability and nutrient retention capacity as well as its large surface area makes it a potential remedy to tackle soil infertility problems. Thus, the addition of biochar to agricultural soils has been projected as a means to improve soil fertility and mitigate climate change (Aydin *et al.*, 2008; Amutio *et al.*, 2013; Rondon *et al.*, 2007; Thies *et al.*, 2009; Wardle *et al.*, 2008). Biochar has the potential to reduce nutrient leaching, thereby improving crop production in coarse-textured soils (Verheijen *et al.*, 2010; Uzoma *et al.*, 2011). Soil nitrogen (N) mineralization rates are affected by biochar amendments, and mainly manure based biochars can be a source of N for plants (Gaskin *et al.*, 2008). Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and also provide a habitat for beneficial microorganisms to flourish (Glaser *et al.*, 2002, Lehmann and Rondon, 2006, Warnock *et al.*, 2007).

Moreover, biochar is considered to be relatively stable in soil with mineralization rates that are slower than that found in the original biomass (Spokas *et al.*, 2010). Based on a long term study, biochar from rice residues was found to be beneficial in rice-based systems, but the actual effect on soil fertility and organic carbon depended on site-specific conditions (Haefele *et al.*, 2011). Based on the studies, pH increased with the biochar amendment, especially in the long-term (Rondon *et al.*, 2007; Haefele *et al.*, 2011; Zhang *et al.*, 2010a). The increase in pH in acidic soils had the effect of alleviating the aluminium toxicity in *Ultisols*. It can improve cation exchange capacity (CEC) so that it increases the bioavailable P and base cations that are responsible for soil fertility (Peng *et al.*, 2011).

Additionally, the porous structure of biochar that retained water and improved water balance resulted in better nutrient availability. However, the duration of this positive impact is not known. Biochar amendments also increased the soil organic carbon (SOC) and total N (Zhang *et al.*, 2010b; Beck *et al.*, 2011). Biochar amendments can also increase the soil organic matter (SOM) (Zheng *et al.*, 2010).

However, most biochar materials are not substitutes for fertilizer, so adding biochar without necessary amounts of nitrogen (N) and other nutrients cannot be expected to provide improvements to crop yield.

Amaranthus cruentus is a highly cherished leafy vegetable in Nigeria because of its high nutritional value. It requires more nitrogen for its luxuriant vegetation, but nitrogen being a very mobile element is prone to leaching losses during heavy rainfall. Hence the need to fortify urea fertilizer supplying nitrogen with biochar to assess the potential impacts of their combinations on selected soil properties, nutrient uptake and dry matter yield of *Amaranthus* plant and in particular, evaluating the critical application levels in a typical rainforest *Ultisol*.

2.0. Materials and Methods

2.1. Description of the Study Area

A pot trial was conducted in the screen – house of the University of Calabar Teaching and Research Farms, Calabar, Cross River State. The area is characterized by a tropical climate which is controlled by high rainfall. It has a mean annual rainfall of 2360 mm with a bimodal distribution pattern, having a distinct dry season of 3 – 4 months. The two peak patterns of rainfall in Calabar are exhibited from June to July and September to October. During the rainy season, there is a short break called "August Break" which lasts for about two weeks. Ambient temperature and relative humidity are high throughout the year. The mean minimum temperature varies between 21^0 C and 24^0 C, and the mean maximum temperature ranges from 27^0 C and 30^0 C. The mean relative humidity varies between 60 to 90 % (Simon, 2010).

2.2. Preparation of Research Materials

Forty-five (45) plastic buckets of 10 L capacity were perforated at the bottom to allow for easy drainage of water. Biochar made from wood feedstock was milled using a mechanical blender and sieved with a 4 mm size plastic sieve to obtain its smooth fine powder. *Amaranthus* seeds and urea were obtained from the Agricultural Development Project (ADP) office in Calabar, Cross River State.

Topsoil was taken at a depth of 0 – 20 cm from the University of Calabar Teaching and Research Farms with the help of a spade. Soil samples collected were air-dried and sieved using a 4 mm size plastic sieve. Ten kilograms (10 kg) of the sieved soil was weighed to all the forty-five (45) plastic buckets and placed in the screen house.

2.3. Experimental Design, Treatment Allocation, Planting and Maintenance

The experimental design used was completely randomized design (CRD) with eight treatments consisting of sole use of biochar at 20 t/ha being regarded as full dose, sole use of urea fertilizer at 60 kg N/ha as full dose and their various combinations. The combinations were ½Biochar + ½Urea, ¾ Biochar + ¼ Urea, ¼ Biochar + ¾ Urea, Full Biochar+ ½ Urea, ½ Biochar + Full Urea and a Control where no amendment was applied. These treatments were replicated three (3) times to give a total of twenty-four experimental units. To each of the experimental units containing 10 kg of soil, the various treatments were applied. Biochar was added to specified pots and thoroughly mixed with the soil, watered to field capacity and left for two (2) weeks before sowing *Amaranthus* seeds to allow mineralization to take place. *Amaranthus* seeds were directly sown into the pots, and the seedlings were later thinned to two plants per pot after few days of emergence. Urea fertilizer treatment was applied to specified pots two weeks after planting using the ring method of application.

For crop maintenance, weeds were handpicked, and crops were watered every evening using 0.25 L of water per pot.

2.4. Soil sampling and processing

Composite soil samples were taken before the experiment while at the end of the experiment, soil samples were taken per pot, air – dried, sieved with a 2 mm size sieve and stored for onward analysis.

2.5. Plant sampling/processing and dry matter determination

Plant samples were obtained at the end of the experiment by uprooting the two plants from each pot. The uprooted plants were rinsed, oven-dried at 65^0 C and weighed to obtain the dry matter yield. The oven-dried plant samples were milled and stored for laboratory analysis.

2.6. Laboratory Analysis

Samples of biochar and soil were subjected to chemical analysis using standard procedures as outlined by Udo *et* *al.* (2009). Particle size distribution was determined by the Bouyoucous hydrometer method. Soil pH was determined in 1:2.5 soil: water ratio with a pH meter. Organic carbon was determined by Walkley Black Dichromate Oxidation Method. Total nitrogen (N) was determined by the micro Kjeldahl method. Available phosphorus (P) was extracted by the Bray 1 extraction method, and the content of P was determined colourimetrically using a Technico AAII auto-analyzer (Technico, Oakland, Calif). Exchangeable bases (K, Na, Ca, and Mg) were extracted with 0.1*N* ammonium acetate; K and Na were read with a flame photometer while Ca, and Mg were determined through the EDTA titration method. Exchangeable acidity was determined by leaching the soils with 1*N* KCl and titrating aliquots with 0.01 NaOH. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity (H and Al). Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and multiplying by 100.

2.7. Plant analysis

The oven-dried milled plant samples were digested using the nitric, perchloric acid mixture. Then nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and Magnesium (Mg) were determined as described by Udo *et al.* (2009).

2.8. Nutrient uptake determination

Nutrient uptake by plants was determined by multiplying the nutrient concentration in the plant samples by the dry matter yield.

2.9. Statistical analysis

Data collected were subjected to Analysis of Variance (ANOVA) using Genstat (2007) and significant means compared using the Duncan New Multiple Range Test (DNMRT) at 5 % level of probability.

3.0. Results and Discussion

3.1 Properties of the soil and biochar used for the experiment

Table 1 shows the nutrient composition of the soil used for the study. The result of the particle size analysis (sand = 83.30 %, silt = 13.00 % and clay = 3.70 %) showed that the soil was loamy sand in texture and strongly acidic (pH 5.1). The values of organic carbon (1.15 %), total nitrogen (0.08 %) and potassium (0.11 cmol/kg) of the experimental soil were below the critical minimum for Nigerian soils (Aduayi *et al.*, 2002). The available phosphorus (31.02 mg/kg) was high. Exchangeable bases (Ca, 2.4 cmol/kg; Mg, 1.2 cmol/kg; K, 0.11 cmol/kg, Na, 0.07 cmol/kg) were low indicating low fertility status and may be due to high rainfall which causes erosion and Leaching away of bases thus the need to fortify biochar with urea to ascertain its ability to adsorb nutrients and prevent loses.

The nutrient concentration of biochar was 1.3 % N, 0.05 % P, 1.72 % K, 1.92 % Ca and 1.05 % Mg, with an alkaline pH of 7.8 and had an organic carbon content of 35.9 % (Table 2). This confirms the report by Chintala *et al.* (2014), who stated that biochar contains an ash component that is usually alkaline and therefore could potentially increase soil pH if added to acidic soil. The organic carbon content of the biochar used falls within that reported by Chan and Xu (2009), who stated that organic carbon in biochar could vary from 0 – 91 %. The high C: N ratio shows the potential of the biochar to decompose slowly.

Table 1: Nutrient composition of the studied soil (0-20 cm)

Parameter	Value
Sand (%)	83.30
Silt (%)	13.00
Clay (%)	3.70
Textural class	Loamy sand
pH (H_2O)	5.1
Organic carbon (%)	1.15
Total Nitrogen (%)	0.08
C: N ratio	14.38
Organic matter (%)	1.98
Available P (mg/kg)	31.02
Ca^{2+} (cmol/kg)	2.40
Mg^{2+} (cmol/kg)	1.20
K^{+} (cmol/kg)	0.10
Na^{+} (cmol/kg)	0.06
H^{+} (cmol/kg)	1.20
Al^{3+} (cmol/kg)	0.20
ECEC (cmol/kg)	5.16
Base Saturation (%)	72.87

3.2. Impact of biochar fortified with urea fertilizer on selected soil properties

The application of the amendments significantly ($P< 0.01$) increased the pH level of the soil when compared with the unamended soil (control)as shown in Table 3. Soil pH was raised from the strongly acidic level of 5.10 and 5.330 obtained before experiment and control, respectively to values ranging from 5.833(moderately acid) to 6.500

Table 2: Nutrient composition of the wood biochar

Parameter	Wood biochar
pH (H_2O)	7.8
Organic carbon (%)	35.9
Total Nitrogen (%)	1.3
C: N ratio	27.61
Organic matter (%)	62.53
Available P (mg/kg)	0.05
Ca^{2+} (cmol/kg)	1.72
Mg^{2+} (cmol/kg)	1.05
K^{+} (cmol/kg)	1.92
Na^{+} (cmol/kg)	6.19

(slightly acid). The highest pH value was obtained in the soil amended with Full B + ½U (6.500), followed by ¾B + ¼U (6.433) and then biochar alone (6.267). Apart from the control soil (5.330), the least pH value amongst the treatments was from the urea alone treated soil (5.833) and this was significantly (P< 0.01) lower than the values in other treated soils except for the ½B + Full U treated soil. This means that biochar, combined with less of urea fertilizer helps in reducing soil acidity than when only urea or full urea is combined. This could be as a result of the basic cations contained in the biochar. Therefore, combining biochar with urea fertilizer is of added advantage in raising the pH level of acidic soils. The result confirms the assertion made by Chintala *et al.* (2014) that biochar contains an ash component that is usually alkaline and could potentially increase soil pH if added to acidic soils. Several other studies by Rondon *et al.* (2007), Zhang *et al.* (2010a) and Haefele *et al.* (2011) have reported significant increases in soil pH as a result of biochar addition in acidic soils. The increase in pH in acidic soils had the effect of alleviating the aluminium toxicity in *Ultisols*. It can improve cation exchange capacity (CEC) so that it increases the bioavailable P and base cations that are responsible for soil fertility (Peng *et al.*, 2011).

Soil organic carbon content was significantly (p< 0.05) increased by the application of Full B + ½U, ¾B + ¼U and½B + ½PM when compared with the control. Sole application of biochar did not increase the soil organic carbon content when compared with the control. This is contrary to the report of Zheng *et al.* (2010) and Beck *et al.* (2011) who reported an increase in soil organic carbon when biochar alone was applied.

Amongst the treated soils, the highest soil organic carbon was obtained in pots amended with Full B + ½U, and the least was from the urea alone treated soil. The increase in soil organic carbon in soils amended with urea and fortified with biochar showed that large amounts of carbon are introduced by biochar application (Adeyemi and Idowu,2017). Significant differences in soil C: N ratio amongst treatments were observed with increases in the order: Full B + ½ U > ½ B + ½ U > biochar alone >½ B + Full U> Control >¼ B + ¾ U> urea alone >¾ B + ¼ U. The C: N ratios obtained were low and below 30:1 as given by Agbede (2009), implying that microbial activities would significantly improve in the soils. Agbede (2009) stated that activities of microbes are impaired when the C: N ratio is greater than 30:1 which could lead to immobilization of soil N. Ibiremo and Akanbi (2015) also recorded significant differences in soil C: N ratio when cocoa pod husk biochar either with or without inorganic fertilizer was used in amending soils grown with kola seedling in Ibadan.

Table 3: Impact of biochar fortified with urea fertilizer on selected soil properties

Treatment	Soil properties				
	pH (H_2O)	O.C (%)	Total N (%)	C: N	Av. P (mg/kg)
Control	5.330h	1.167f	0.11de	12.00d	9.00c
Urea alone (60 kg N/ha)	5.833g	1.217ef	0.10e	11.67e	15.06b
Biochar alone (20 t/ha)	6.267bcde	1.470cdef	0.12de	12.25c	25.96a
½ B + ½ U	6.167def	1.280def	0.10de	12.80b	24.91ab
¾ B + ¼ U	6.433abcd	2.437ab	0.21a	11.61e	19.92ab
¼ B + ¾ U	6.233cdef	2.113bcde	0.18abc	11.74e	20.20ab
Full B + ½ U	6.500abc	3.060a	0.19ab	16.11a	21.75ab
½ B + Full U	5.933fg	1.320def	0.10e	12.17cd	23.33ab

Mean values followed by the same letter(s) within the same column are not significantly different according to DNMRT at 5 % probability.

The amendments applied significantly (p<0.05) increased the total nitrogen content of the soil with the highest value (0.21%) obtained in soils treated with ¾ B + ¼ U (15 t/ha Biochar + 15 kg N/ha urea) and was significantly higher than the values obtained in other amended soils and control except soils amended with ¼B + ¾ U and Full B + ½ U. The soil with the least total nitrogen content (0.097%) was the one amended with urea alone (60 kg N/ha), but it was higher than the N- content in the soil before the experiment (0.08%).

The highest value for available phosphorus (25.96 mg/kg) was obtained in soils treated with biochar alone, but it was not significantly higher than all other amended soils except the urea treated soil and the control. However, there was generally a reduction in soil available phosphorus status compared with the initial value of 31.02 mg/kg before the experiment. This reduction might be attributed to the uptake of phosphorus by the *Amaranthus* plant.

The positive increases in the soil properties obtained in this study conform with the reports given by other researches (Lehmann *et al.*, 2003; Liang *et al.*, 2006; Yusif *et al.*, 2016). They showed that additions of biochar to soil increases the availability of major cations, total nitrogen and phosphorus. Similarly, Biederman and Harpole (2013) reported an increase in soil phosphorus (P), potassium (K), total nitrogen (N), and organic carbon (C) with biochar addition compared with the control. Yusif *et al.* (2016) reported significant differences (p<0.05) in soilpH, organic carbon, nitrogen, phosphorus and Ca among biochar rates with 20 t/ha of biochar producing higher value when compared with 10 t/ha and 0 t/ha (control) in most cases. This higher nutrient availability for plants in the soil is attributable to both the direct nutrient additions by the biochar and greater nutrient retention (Lehmann *et al.*, 2003; Yusif *et al.*, 2016). This is in line with the assertions made by Adeyemi and Idowu (2017) that biochar is considered much more effective than other organic amendments in retaining and making nutrients available to plants.

3.3. Impact of biochar fortified with urea fertilizer on nutrient uptake of Amaranthus cruentus

There were significant (p< 0.05) increases in N – uptake of *Amaranthus* cruentus plants grown in treated soils when compared with the control (Table 4). The highest N – uptake was obtained from plants amended with urea alone (0.0733 mg/kg) though not statistically different from the values obtained from all the other treated plants. The least uptake of N in control soil as observed in this study agreed with reports of Iren *et al.* (2012), Nwachukwu *et al.* (2013) and Ibiremo and Akanbi (2015) who observed that nutrient content of fertilizer determine the uptake of such nutrient by plants.

The uptake of P in *Amaranthus* cruentus plants was significant (p< 0.05) in all the treated soils relative to the control. The highest P – uptake was obtained in soil amended with Full B + ½ U (0.0057 mg/kg) which was statistically different from all the other amended soils. This is similar to the observation made by Iren *et al.* (2016) who observed increases in P – uptake of *Amaranthus cruentus* in soils amended with pig and poultry manures relative to the control. The highest K – uptake was obtained from the application of Full B + ½ U (0.0753 mg/kg) and was statistically similar to those obtained in sole urea and biochar treated plants including the ½ B + ½ U but was significantly higher than the K-uptake in plants treated with ¾ B + ¼ U, ¼ B + ¾ U, ½ B + Full U and the control. The increase in uptake of nutrients by Amaranthus plants observed in this study especially when biochar is fortified with urea fertilizer shows that the large surface area exhibited by biochar and its micro-pore structure is favourable to bacteria and fungi that are needed by plants to absorb nutrients from the soil (Adeyemi and Idowu, 2017).

There was no significant difference in the plant uptake of magnesium among treatments and when compared with the control.

3.4. Impact of biochar fortified with urea fertilizer on dry matter yield of Amaranthus cruentus

Dry matter yield of *Amaranthus* was significantly (P < 0.05) increased by treatments applied with the highest yield of 0.96 t/ha obtained from the combination of Full B + ½U, followed by ½B + Full U treated plants (0.84 t/ha) while the least was from the control (0.46 t/ha). This is similar to the result obtained by Iren *et al.* (2016) who recorded an increase in the dry matter yield of *Amaranthus* as a result of amendments applied when compared with that of the untreated plants.

4.0. Conclusion

From the results, it has been shown that combining biochar with urea fertilizer was more effective than when each was

Table 4: Impact of biochar fortified with urea fertilizer on nutrient uptake of *Amaranthus cruentus*

Treatment	Nutrient uptake (mg/kg)				
	N	P	K	Ca	Mg
Control	0.0160b	0.0010c	0.0012c	0.0010c	0.0200a
U – alone	0.0733a	0.0033b	0.0507ab	0.2980a	0.0340a
B – alone	0.0540a	0.0033b	0.0520ab	0.0350b	0.0177a
½ B + ½ U	0.0467a	0.0030b	0.0487ab	0.0450b	0.0380a
¾ B + ¼ U	0.0430a	0.0030b	0.0370b	0.0290b	0.0170a
¼ B + ¾ U	0.0567a	0.0033b	0.0400b	0.0440b	0.0233a
Full B + ½ U	0.0473a	0.0057a	0.0753a	0.0490b	0.0233a
½ B + Full U	0.0340a	0.0023b	0.0343b	0.0290b	0.0193a

*Mean values followed by the same letter(s) within the same column are not significantly different according to DNMRT at 5 % probability.

Table 5: Influence of sole and complimentary use of biochar, poultry manure and Urea on dry matter yield of Amaranthus cruentus

Treatments	Dry matter yield (g/pot)	Dry matter yield (t/ha)
Control	2.27 c	0.46c
U – alone	3.60b	0.78b
B – alone	3.87b	0.72b
½B + ½U	3.50 b	0.70b
¾B + ¼U	2.97 b	0.61b
¼B + ¾U	3.67b	0.73b
Full B + ½U	4.80 a	0.96a
½B + Full U	3.20 b	0.84a

Mean values followed by the same letter(s) within the same column are not significantly different according to DNMRT at 5 % probability.

applied singly. The combination of biochar with urea fertilizer improved the chemical properties of the soil, nutrient uptake and dry matter yield of *Amaranthus* more than their single application. This means that by fortifying biochar with urea, soil fertility will be dramatically improved and fertilizer demand reduced. Therefore, the fortification of biochar with urea especially more of biochar and less of urea is recommended for improved soil productivity and optimal performance of *Amaranthus cruentus* in an acidic rainforest Ultisol.

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