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Effect of Biochar on Macronutrients Release and Plant Growth on Degraded Soil of Lafia, Nasarawa State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author EN designed the study, wrote the protocol and wrote the first draft of the manuscript. Author JIO reviewed the experimental design and all drafts of the manuscript. Authors DAB and JAO managed the analyses of the study. Author DAB identified the plants. Authors EN and JIO performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

This study consisted of laboratory incubation and pot experimentation. Laboratory incubation was conducted at the Chemistry Laboratory, College of Agriculture, Lafia. The pot experimentation was done in the screen house of faculty of Agriculture, Nasarawa State University Lafia campus during the dry season of 2015 to assess weekly macronutrients (NPK) release in soil amended with locally produced sawdust and rice husk biochar and the growth and nutrient uptake of maize grown on the same soil. The experimental design used was complete randomized design (CRD) and the treatments consisted of three levels of rice and sawdust biochar: 0, 60, 120 g factorially combined to form 9 treatments. The result showed that, in the first week of incubation, 120 g of rice husk and sawdust biochar produced the highest levels of pH (6.58 and 6.69), Nitrogen (0.56 gkg^{-1} and 0.48 gkg^{-1}), available phosphorus (27.61 $mgkg^{-1}$ and 27.73 $mgkg^{-1}$) and potassium (0.26 $cmolkg^{-1}$ and

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0.23 cmolkg^{-1}) respectively. However, the second week of incubation recorded a reduction in nitrogen (0.39 gkg^{-1} and 0.44 gkg^{-1}) released with application rates of 120 g of both rice husk and sawdust biochars respectively. There was increased in available phosphorus (35.00 mgkg^{-1} and 37.20 mgkg^{-1}) and potassium (0.26 cmolkg^{-1}and 0.23 cmolkg^{-1}) and soil pH (6.73 and 6.88) respectively in the second week. In the third week of incubation, there was a continuous decline in soil N (0.35 gkg^{-1} and 0.36 gkg^{-1}) but, P. K and soil pH consistently showed an increase. Rice husk and sawdust biochar applied at 120 g was significantly (p<0.05) higher in a number of leaves (7.00 and 8.00); growth height (50.73 cm and 20.67 cm); fresh weight (102.82 g and 26.18 g); dry weight (15.11 g and 2.69 g) respectively. N P and K uptake by maize plants were also significantly (P<0.05) influenced by rice husk biochar application. 120 g of rice husk biochar produced the highest value of maize uptake of N (2.51 gkg^{-1}); P (62.62 mgkg^{-1}) and K (4.28 cmolkg^{-1}). Then, 120 g of saw dust biochar produced maize that took in the highest values of N (3.70 gkg^{-1}); P (59.40 mgkg^{-1}) and K (4.00 cmolkg^{-1}).

Keywords: Biochar; macronutrients; plant; growth; soil.

1. INTRODUCTION

The essential elements (N, P, K, Ca, S and Mg) used by plants in relatively large amounts for their growth are called macronutrients and all of these five nutrients are important constituents in soil that promote plant growth and yield [1]. The threats of soil nutrient depletion associated with global warming and food insecurity are growing global problems. Climate change and continuous cropping of the same land have further put more pressure on the nutrient supply of agricultural lands. Soil nutrient deficiency in agriculture is of prime concerns particularly in developing countries such as Nigeria that is suffering from wind erosion and desertification from the North and water erosion especially in the Southeastern Nigeria [2]. These phenomena give birth to soils that are deficit in soil organic matter; which influences the availability of macro nutrients. Although several options have been proposed for contending with these issues, no single solution has been found. However, biochar technology has been proposed to offer an integrated approach to contribute to the solution of these challenges [3]. Biochar is the carbon-rich product that remains when heating natural organic materials: crop biomass, woodchips, manure and other agricultural waste of different plant origin is heated to a high temperature below 1000℃ in reduced oxygen conditions [4]. The addition of biochar to soils is an ancient practice that has only recently attracted the attention of scientists and is strongly promoted by many as a way to sequester carbon while improving soil properties. The addition of biochar as amendment materials to degraded soils is receiving a global attention due to the apparent benefits of biochar to soil quality and enhancement of crop yields, as well as the potential of biochar to actively sequestered carbon [5]. An understanding of the chemical changes that occur in biochar-amended soils is a key in managing agricultural soils. This is particularly of importance because the application of biochar to soils as an amendment has shown some physical and chemical advantages. Before considering the influence of biochar on macro-nutrient release, the nutrient content in biochar must be considered first. In other words, does biochar serve as a significant source of nutrients irrespective of other inputs? The addition of biochar to forest soils has been found to directly influence nitrogen transformations in phenol-rich acidic forest soils of both temperate and arboreal forest ecosystems [6]. Also, applying biochar to forest soils along with natural or synthetic fertilizers has been found to increase the bioavailability and plant uptake of phosphorus, alkaline metals and some trace metals [7]. It is important to note that nutrient in biochar is somewhat depleted during the pyrolysis or oxidation process that generates biochar. Heating causes some nutrients to volatilize, especially at the surface of the material; while other nutrients become concentrated in the remaining biochar. Some individual elements are potentially lost to the atmosphere; others are fixed into recalcitrant forms or liberated as soluble oxides during the heating process. In the case of wood based biochar formed under natural conditions, carbon begins to volatilize around 100℃, Nitrogen above 200℃, Sodium above 375℃, potassium and Phosphorus above 700℃ [8]. Therefore, biochar is likely more important as a soil conditioner and driver of nutrient release and less of a primary source of nutrients [7]. [9] recommended the use of sawdust and rice husk biochar for soil amendment. This is because the goal of any soil amendment is to provide a better and more nourishing environment for plant roots. For soil amendment to work, the amendment materials must be thoroughly mixed within the soil. If it is just placed under the soil, it can interfere with movement of water or air and the growth of the plant roots can be affected [10]. [11] reported improvement in both physical and chemical properties of degraded soil when sawdust and rice biochar were incorporated into the soil. However, the explanation of the mechanism of soil nutrients release as influenced by biochar amendment is a complex phenomenon that required rigorous investigation. Therefore, this study is intended to provide information on weekly assessment of macronutrients (NPK) release in soil amended with locally produced sawdust and rice husk biochar and evaluate the growth and nutrient uptake of maize grown on the same soil.

2. MATERIALS AND METHODS

The study consisted of laboratory and pot experiments. The incubation study was conducted at the chemistry Laboratory, College of Agriculture, Lafia, and the pot experiment was done in the screen house of faculty of Agriculture, Nasarawa State university Lafia campus during the dry season of 2015. The study area falls within Southern Guinea Savanna Agroecological Zone of Nigeria, and is located between Latitude 08.33 N and Longitude 08.32 E. Rainfall usually starts from May – October and the average monthly rainfall figures ranges from 40 mm - 350 mm. The months of July and August usually records heavy rainfall. The daily maximum temperature ranges from 20.0℃ – 38.5℃ and daily minimum ranges from 18.7℃ – 28.2℃. The months of February to early April are the months that have the highest maximum temperature while the lowest maximum temperature months are recorded in December and January. Relative humidity rises from April to a maximum of 75- 90 percent in July [12].

2.1 Soil Sample Collection

Top soil was collected at a depth of 0-15 cm with soil auger from the teaching and research farm of college of Agriculture, Lafia, Nasarawa state Nigeria; for screen house pot experiment. Then 5 kg of the soil obtained was filled into 9 plastic buckets which is equal to the number of treatment and replicated three times to produced 27 plastic buckets.

2.2 Local Production of Biochar

Feed stocks of rice husk and sawdust were collected from rice mill and timber shade in Lafia for the production of biochar. An improvised kiln was constructed, which was an empty drum that was perforated but had a cover. The rice husk materials were poured inside the drum half full, then was ignited inside the drum and the drum lid was covered to encourage slow burning and the content in the drum was consistently stirred to enhance uniformity of burning. After 3-4 hours the content of drum is poured out and the fire was quenched by sprinkling water on the hot char. Rice husk biochar was finally dried in the sun. The same procedures were applied for local production of sawdust biochar.

2.3 Experimental Design and Treatment

The experimental design used was complete randomized design (CRD) and the treatments consisted of three application rates of both rice husk and sawdust biochar: 0, 60, 120 $g5kg^{-1}$ of soil factorially combined and replicated three times and laid out in the screen house. NPK 15:15:15 fertilizer was applied on each pot at the rate of 35 g per pot.

2.4 Laboratory Incubation Study

Out of the 5 kg of soil above incorporated with the treatments; 1000 g of the same soil per treatment was collected and incubated at water content close to the field capacity and temperature of 15℃ for 28 days. At the end of every week (seven days); 100 g of the incubated soil was collected for macronutrients (NPK) and soil pH analyses.

2.5 Screen House Study

The three biochar application rates (0, 60 and 120 g) were equivalent to 0 t ha^{-1}, 26.90 t ha^{-1} and 53.81 t ha^{-1} respectively. Maize seeds of Oba 98 were planted in each pot as the test crop and later thin to one plant per pot. Weeding and other agronomic practices were carried out. At four weeks after planting; maize growth parameters were measured included: plant height, number of leaves. The maize plant was harvested and oven dried at 45℃ for tissues analysis using standard methods as described by [13]. Finally, soil samples from each plastic bucket were also taken for post-harvest laboratory soil analysis.

2.6 Laboratory Analyses of Soil and Biochar

All soil samples (soil sample before incorporating the treatments and soil samples after harvest) collected were air-dried, and gently crushed, then passed through 2 mm sieve to obtain a homogeneous particle size, after which both physical and chemical properties of these samples were determined before incorporating with biochar and only NPK and soil pH were analyzed after collecting plant sample. The prepared biochars (sawdust and rice husk biochar) were also subjected to routine analysis of their chemical composition using standard methods as described by [13]. Then N, P and K uptake of maize was determined by nutrient concentration in maize plant tissue multiply by total plant dry matter [14].

2.7 Data Analysis

The data collected were subjected to analysis of variance for RCBD using GENSTAT software, and where there was a significant difference; the means were separated using F-LSD at 5% probability level.

3. RESULTS AND DISCUSSION

The soil was very sandy and low in nitrogen, phosphorus, potassium, organic carbon and cation exchange capacity (Table 1). Also, the soil was slightly acidic in nature (pH 6.02 in H_2O and 6.00 in 0.01M KCl).

The chemical properties of biochars used in this study are presented in (Table 2). The pH of rice husk biochars used was almost neutral (7.14) and sawdust biochar was strongly alkaline (9.33). Rice husk biochar had higher quantities of total nitrogen of 6.3 gkg^{-1}, organic carbon 20.7 gkg^{-1} compared with the sawdust biochar. However, the sawdust biochar had higher quantities of ashes (4.25 gkg^{-1}) compare to the rice husk biochar. The C/N ratio of rice husk biochar was 8.05 gkg^{-1}; while the C/N ratio of sawdust biochar was 17.71 gkg^{-1}. The sawdust biochar material contained higher quantities of carbon and carbon /nitrogen ration than rice husk biochar (Table 2). The cation exchange capacities of both sawdust and rice husk biochars were very low; but the percentage base saturation of both biochars were very high (88% sawdust biochar and 96% rice husk biochar).

Table 1. Laboratory analysis of soils at 0-15 cm before incorporating biochars

Mech composition				Chemical composition											
Sand	**Silt**	**Clay**	**TCL**	**pH**	**pH**	**TN**	**Av.P**	**OC**	**K**	**Mg**	**Ca**	**Na**	**Al+H**	**CEC**	**BS**
	(%)			**H_2O**	**KCl**		**(gkg^{-1})**		**($mgkg^{-1}$)**			**$cmolkg^{-1}$**			**(%)**
85.50	3.40	11.6	LS	6.02	6.00	0.25	5.67	6.40	0.31	1.78	3.41	0.67	0.83	6.17	87.02

TCL = Textural class TN = Total Nitrogen

Table 2. Chemical properties of biochar used for the trials

Chemical composition	Sawdust	Rice husk
pH(H_2O)	9.33	7.14
pH(KCl)	9.07	7.03
Ashes(gkg^{-1})	42.5	35.6
T N(gkg^{-1})	2.8	6.3
OC(gkg^{-1})	49.6	50.7
C/N(gkg^{-1})	17.71	8.05
Av. P($mgkg^{-1}$)	8.01	6.01
K($cmolkg^{-1}$)	0.32	0.31
Mg($cmolkg^{-1}$)	1.28	1.34
Ca($cmolkg^{-1}$)	3.68	3.01
Na($cmolkg^{-1}$)	0.69	0.52
Exch. Acidity ($cmolkg^{-1}$)	0.70	0.20
CEC($cmolkg^{-1}$)	5.97	5.18
%Base Saturation	88	96

TN=Total Nitrogen C/N=Carbon Nitrogen Ratio

Table 3. Effect of biochar on NPK concentration after three weeks of incubation

Treatment	**pH (H_2O)**	**N (gkg^{-1})**	**P ($mgkg^{-1}$)**	**K ($cmolkg^{-1}$)**	**pH (H_2O)**	**N (gkg^{-1})**	**P ($mgkg^{-1}$)**	**K ($cmolkg^{-1}$)**	**pH (H_2O)**	**N (gkg^{-1})**	**P ($mgkg^{-1}$)**	**K ($cmolkg^{-1}$)**
RHB(g)		**7 days of incubation**				**14 days of incubation**				**21days of incubation**		
0	6.01	0.23	23.01	0.20	6.03	0.22	26.00	0.17	6.02	0.20	30.01	0.21
60	6.34	0.38	25.03	0.21	6.57	0.30	27.00	0.20	6.68	0.29	30.00	0.23
120	6.58	0.56	27.61	0.26	6.73	0.39	29.00	0.21	6.79	0.35	31.10	0.30
SDB(g)												
0	6.05	0.20	24.50	0.20	6.05	0.20	27.90	0.19	6.05	0.20	30.00	0.17
60	6.38	0.47	26.41	0.24	6.72	0.41	28.10	0.20	6.84	0.30	30.10	0.19
120	6.69	0.48	27.75	0.28	6.88	0.44	29.20	0.22	6.92	0.36	31.00	0.20
LSD(0.05)	0.25	0.12	1.20	0.03	0.23	0.11	0.09	0.03	0.23	0.09	1.90	0.02
C.V%	3.21	18.72	7.42	28.31	3.00	69.5	2.65	16.40	3.00	50.01	6.34	22.00
Interaction												
RHBxSDB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

RHB= Rice husk biochar SDB=Sawdust biochar NS= Not significant C.V = Coefficient of variability

The result showed that both rice husk and sawdust biochar rates significantly ($p<0.05$) increased release of N P K and soil pH in the incubatory study (Table 3). In the first week of incubation, 120 g of rice husk and sawdust biochar produced the highest levels of pH (6.58 and 6.69), Nitrogen (0.56 gkg^{-1} and 0.48 gkg^{-1}), available phosphorus (27.61 $mgkg^{-1}$ and 27.73 $mgkg^{-1}$) and potassium (0.26 $cmolkg^{-1}$ and 0.23 $cmolkg^{-1}$) respectively. However, the second week of incubation recorded a reduction in nitrogen (0.39 gkg^{-1} and 0.44 gkg^{-1}) released with application rates of 120 g of both biochars; but increased in available phosphorus (35.00 $mgkg^{-1}$ and 37.20 $mgkg^{-1}$) and potassium (0.26 $cmolkg^{-1}$ and 0.23 $cmolkg^{-1}$) and soil pH (6.73 and 6.88) respectively. In the third week of incubation, there was continuous decline in soil N (0.35 gkg^{-1} and 0.36 gkg^{-1}) but, P, K and soil pH consistently showed increase.

Rice husk and saw dust biochar had a significant ($P<0.05$) effect on all growth parameters of maize plant assessed (Table 4). Rice husk and sawdust biochar applied at 120 g was significantly ($p<0.05$) higher in number of leaves (7.00 and 8.00); growth height (50.73 cm and 20.67 cm); fresh weight (102.82 g and 26.18 g); dry weight (15.11 g and 2.69 g). N P and K uptake by maize plants were also significantly ($P<0.05$) influenced by rice husk biochar application. 120 g of rice husk and sawdust biochar produced the highest value of maize uptake of N (2.51 gkg^{-1}); P (62.62 $mgkg^{-1}$) and K (4.28 $cmolkg^{-1}$). Then, 120g of saw dust biochar produced maize that took in the highest values of N (3.70 gkg^{-1}); P (59.40 $mgkg^{-1}$) and K (4.00 $cmolkg^{-1}$).

4. DISCUSSION

The soil of the study area was generally very sandy, low in organic matter, low in soil macro-nutrient (NPK) and also low in exchangeable cations. The soil is moderate to slightly acidic in nature. This confirmed the findings of [15]. The result in table one showed soil that is already degraded due to intensive and continuous cultivation without adequate application of replenishment measures to sustain it productivity. The study also revealed that both the biochars used in the trials had significantly increased the soil pH throughout the period of incubation. This confirmed the findings of [16] who reported a proportional increase in pH values of degraded soil as a result of increased biochar rates applied in the soils of southern guinea savanna agroecolgical zone of Nigeria. This significant reduction in soil acidity may be attributed to the fact that, the biochars possessed ashes that could act as a liming agent (Table 2). There was also a general increase in availability of phosphorus and potassium at first and second week of incubation. This increase in P availability has been reported in the presence of biochar [9]. The mechanisms suggested for biochar influence on P availability is increased in soil pH, which then influences the interaction of P with other cations, or enhanced retention through anion exchange. While, the significant decrease in nitrogen during this period of incubation may be attributed to the fact that biochar additions to agricultural soils in the tropics have been reported to either reduce N availability [17] or to increase N uptake and export in crops [18]. Reduced N availability may be as a result of the high C/N ratio of biochar and, thus, greater

Table 4. Effect of biochar soil amendment on maize growth and macro-nutrient uptake at six weeks after planting

Treatment	No. Leaves	Plant Height(cm)	Fresh weight (g/plant)	Dry weight (g/plant)	(%) N	$mgkg^{-1}$ P	$cmolkg^{-1}$ K
RHB($gpot^{-1}$)							
0	6.56	47.21	84.81	13.45	2.40	47.90	3.27
60	6.67	49.62	91.40	13.92	3.70	55.32	3.83
120	7.00	50.73	102.82	15.11	4.02	62.62	4.28
Total mean	6.74	49.19	93.01	14.16	3.37	55.28	3.79
LSD(0.05)	0.16	1.24	2.81	1.12	0.64	5.85	0.51
SDB($gpot^{-1}$)							
0	6.56	48.21	90.11	13.04	2.99	50.72	3.48
60	6.78	48.42	92.12	14.35	3.43	55.72	3.90
120	6.89	50.10	96.76	14.49	3.70	59.40	4.00
Total mean	6.74	48.91	93.00	13.96	3.37	55.28	3.79
LSD(0.05)	0.16	1.24	2.81	1.12	0.64	5.85	0.51
Interaction							
RHB x SDB	NS	NS	NS	NS	NS	NS	NS

RHB=Rice husk, SDB=Sawdust, NS= no significant effect potential for N immobilization or due to biochar adsorption of NH_4, which in turn reduces the potential for N leaching losses and sustained higher N fertility over time in surface soils [18]. The vigorous growth performance of maize planted on this biochar amended soil could be attributed to the fact that, the soil of this study area had high quantity of sand particles, low clay content and deficient in some macronutrient (Table 4). When biochars were incorporated into the soils it reduces the sizes of the soil pores thereby reducing the leaching of these macro-nutrients and also increased water holding capacity, increased cation exchange capacity (CEC), and provided a medium for absorption of minimal plant nutrients and improved conditions for activities of soil micro-organisms [19]. This explains why amending the soil with biochars brought about this visible improvement in the growth of maize plants. Also, increased application of both biochars resulted to increased quantities of macro-nutrients uptake by maize plant. This is in accordance with the result of [20] who reported similar effect of biochar on N uptake in which it was observed that application of biochar significantly increased N uptake.

5. CONCLUSSION

In the first week of incubation study, increased in rice husk and sawdust biochar application also increased soil pH, Nitrogen, available phosphorus and potassium. However, the second week of incubation recorded a reduction in nitrogen released; but increase in available phosphorus and potassium and soil pH. In the third week of incubation, there was continuous decline in soil N but, P. K and soil pH consistently showed increased. Rice husk and sawdust biochar significantly increased maize number of leaves, growth height; fresh weight and dry weight. N, P and K uptake by maize plant were also significantly higher.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Agbede OO. Understanding soil and plant nutrition: Salmon Press and coyKeffi, Nigeria. 2009;147-15.
2. Sanchez PA. Soil fertility and hunger in Africa. Science. 2002;295:2019–2020.
3. Lehmann J, Joseph S. Biochar for environmental management: An introduction. In Biochar for Environmental Management: Science and Technology. Eds. J Lehmann and S Joseph. Earthscan, London, UK. 2009;1-12.
4. Lehmann J, Hanley K, Hyland C, Rajkovich S, Miller-ter Kuile E, Cheng CH, Enders A. Crop yield, nutrient uptake and leaching, soil water availability, and nitrous oxide emissions with biochar from different feedstocks and produced at different temperatures. Biochar: Sustainability and security in a changing climate. Proceedings of the 2nd International Biochar Initiative Conference, Newcastle; 2008.
5. Major J. Biochar: A new soil management tool for farmers and gardeners. Appalachian Sustainable Development. IBI report; 2011.
6. DeLuca TH, Sala A. Frequent fire alters nitrogen transformations in ponderosa pine stands of the inland northwest. Ecology. 2006;87:2511–2522.
7. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. Biol Fertil Soil. 2002;35:219–230.
8. Knoepp JD, DeBano LF, Neary DG. Soil Chemistry, RMRS-GTR 42-4, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT; 2005
9. Ndor E, Jayeoba OJ, Asadu CLA. Effect of biochar soil amendment on soil properties and Yield of Sesame Varieties in Lafia, Nigeria. 2015;9(4):1-8.
10. Davis JG, Wilson CR. Choosing a soil amendment. Colorado State University Extension; 2012.
11. Ndor E, Amana SM, Asadu CLA. Effect of biochar on soil properties and organic carbon sink in degraded soil of southern guinea Savanna Zone, Nigeria. International Journal of Plant & Soil Science. 2015;4(3):252-258.
12. NIMET. Nigerian Meteorological Agency. Lafia station; 2015.
13. Agbenin JO. Laboratory manual for soil and plant analysis (Selected methods and data analysis). Published by the Author. Zaria. 1995;24-44.
14. Mahadi MA. Growth, nutrient uptake and yield of maize (*Zea mays* l.) as influenced

by weed control and poultry manure. International Journal of Science and Nature. 2014;5(1):94-102.
15. GENSTAT. Statistical software package for biological and agricultural students; 2008 edition.
16. Jayeoba OJ, Sangari DU, Alabi RT. Geostatistical analyses of the spatial variation of soil reaction (pH) in Nasarawa State, North Central Nigeria. International Journal of Science and Advanced Technology. 2012;2:5:2012. (ISSN 2221-8386)
17. Lehmann J, da Silva Jr, JP, Steiner C, Nehls T, Zech W, Glaser B. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertilizer, manure and charcoal amendments. Plant and Soil. 2003;249:343–357.
18. Steiner C, Das KC, Garcia M, Förster B, Zech W. Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic Ferralsol. Pedobiologia. 2008;51:359-366.
19. Sohi S, Lopez-Capel E, Krull ES, Bol Biochar R, climate change and Soil: A review to guide future research. CSIRO Land and Water Science Report 05/09; 2009.
20. Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance andsoil fertility. Plant Soil. 2010;327:235–246.

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