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Full-Length Research Paper

The influence of Bambara groundnut shells biochar on the early growth of sweet corn variety in the sub-humid tropics

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ABSTRACT: Using biochar from underutilized crops residues such as Bambara groundnut shells could address the problem of crop waste disposal in the sub-humid tropical regions where residue disposal could pose a great difficulty in adoption and integration of these crops into the existing cropping systems. An experiment was conducted at The University of Nottingham Malaysia Campus to study the early performance of corn under varying levels of biochar from Bambara groundnut shells. The treatments consisted of five levels (0, 5, 10, 15 and 20 t ha^{-1}) of biochar laid out in a completely randomized design replicated three times. Data were collected on growth and nutrient content of the crop. The results revealed that application of 10 t ha^{-1} biochar was optimum for number of leaves, leaf area, root dry weight, shoot dry weight, total dry weight, root volume, root surface area, ash content and nutrients uptake whereas, root length was optimum at the application of 5 t ha^{-1}. Other parameters were not influenced by biochar application on the crop. Thus, application of 10 t ha^{-1} was optimum for the increased performance of sweet corn in the study area.

Keywords: Bambara groundnut shell, sweet corn, early growth

INTRODUCTION

Sweet corn (*Zea mays* L. var. saccharata) is a very popular crop in Malaysia since in the early sixties. The cropis grown for fresh consumption and is an important raw material for canned food industries. It contains 3.35 g protein, 10 g oil, 221 g carbohydrates, 0.03 g calcium, 1.11 g phosphorus, 2. 8 g potassium per kg (Ali et al., 2003; Coşkun et al., 2006; Nigussie and Saleh, 2007). The crop is known to be exposed to moisture and other environmental stress conditions during the growing period and as such it requires the adoption of promising production practices which could conserve soil moisture and nutrients for use by the crop (Garcia et al., 2009). Bambara groundnut (*Vignasubterranea* L Verdc.) is among the few underutilized crops identified as having great potential to increase food production in challenging environments where major crops are severely limited by adverse climatic conditions (Mayes et al., 2012). However, any attempt to increase the production or extension of these crops in environments such as the sub-humid tropical regions of Malaysia and Indonesia with the existing problem of crop waste/residue disposal (Murty et al., 2000; Varkkey, 2013; Forsyth, 2014) could face severe challenges unless efforts are made to address the problem. One way the performance of sweet corn could be improved is through the application of biochar to improve soil conditions and nutrient uptake of the crop. Biochar which is a product of thermal decomposition of biomass under oxygen-limited conditions (pyrolysis) (Chen et al., 2011) has been gaining popularity as a strategy for mitigation of climate change, soil remediation and crop waste disposal (Barrow, 2012; Tang et al., 2013) and could serve as a more sustainable way to dispose Bambara groundnut residues (shells).

Biocharis known to keep soil applied nutrients in the topsoil within the root zone of most crops thereby increasing the nutrient use efficiency (Barrow, 2012; Lehmann et al., 2003). It has been reported to raise soil pH, increase the water holding capacity of soils and yield performance of crops (Jeffery et al., 2011). Major et al. (2010) reported biochar application on highly weathered tropical soils to increase the soil nutrients availability and uptake in maize. The present investigation was carried out to study the response of the crop to different levels of Bambara groundnut biochar application.

MATERIALS AND METHODS

Experimental site

A trial was conducted at The University of Nottingham Malaysia Campus, Semenyih, Selangor, Malaysia. The area is located on latitude 2°57"N and longitude 101°51"E at an altitude of 560m above sea level. The climate of the area is Tropical sub-humid with mean annual rainfall of 3000mm. Soil analysis of the experimental site revealed that the soil was strongly acidic (pH H_2O 4.20), low in C (0.48%), N (0.05%), P (2.3 ppm), K (0.10 m.e.%) and CEC (4.5m.e.%). The soil was clayey in texture (Table 1).

Treatments and experimental design

Treatments consisted of five biochar levels (0, 5, 10, 15 and 20 t ha^{-1}) using Bambara groundnut shell biochar (Table 2).

The treatments were laid out in a completely randomized design (CRD) replicated three times.

The procedure for the biochar production and characterization of the Bambara groundnut shells used in the experiment

The Bambara groundnut shell materials were obtained from the Field Research Centre (FRC) of the Crops For the Future, The University of Nottingham Malaysia Campus and oven dried at 105 °C for 24hrs according to BS EN 14774-1: 2009 (*British Standards Institution,* London, UK) procedure. The dried materials were shredded in a Retsch® rotor beater mill to particle sizes between 0.2 mm and 2 mm and stored in air tight plastic bags for further studies. Volatile matter content on dry basis was determined according to BS EN 15148:2009 (*British Standards Institution,* London, UK) and the ash content was determined according BS EN 14775:2009 (*British Standards Institution,* London, UK) procedure. Fixed carbon was computed by subtracting the percentage compositions of ash and volatile matter from the bone dry sample mass. Higher heating value (HHV) was determined using a Parr 6100 oxygen bomb calorimeter using the procedure of BS EN 14918:2009 (*British Standards Institution,* London, UK). The ash inorganic composition was determined using energy dispersive x-ray (EDX) (Oxford instrument X-Max 20 mm^2). Elemental compositions were determined using a Perkin Elmer 2400 Series II CHNS/O analyzer (Perkin Elmer SdnBhd, Selangor, Malaysia). Bio-char was produced from Intermediate pyrolysis of Bambara shell in a fixed bed pyrolysis system. The unit consist of a fixed bed reactor made of stainless steel (115 cm length, 6 cm inner diameter), a distribution plate with 1.5 mm hole diameter which sit at 25 cm from the bottom of the tube, two nitrogen preheating sections, a cyclone, water chiller operating at 4°C attached to a coil condenser, oil collector and gas scrubbers. 200 g of the sample (bone dry, 2 mm particle size) was placed on the distribution plate inside the reactor tube and pyrolysis was conducted under nitrogen atmosphere at 9.5 L min-1 (20SCFH). Pyrolysis temperature of 600°C was used and the reactor was heated electrically at the rate of 30 °C min-1. The reaction temperature was monitored with a K-type thermocouple connected to computer through data logger. The reaction time was kept at 60 min (±2 min) or until no significant amount of non-condensable gas was observed after the reaction temperature reaches 600°C. The bio-char produced was collected and analyzed at the end of the experiment after the reactor was allowed to cool to room temperature. The Elemental compositions of bio-char were determined using a Perkin Elmer 2400 Series II CHNS/O analyzer (Perkin Elmer SdnBhd, Selangor, Malaysia). Scanning electron microscopy (SEM, FEI Quanta 400 FE-SEM) was used to evaluate the surface and structural characteristics of the bio-char. Specific surface area (BET) and pore properties of the

Table 1: Physico-chemical properties of the soil used during the experiment at the University of Nottingham, Malaysia Campus.

Properties	Values
Chemical Properties	
pH (H_2O)	4.20
P (ppm)	2.3
Carbon (%)	0.48
Total N (%)	0.05
Exchangeable cations (meq %)	
K	0.10
Ca	1.16
Mg	0.12
Na	0.09
Al	0.67
CEC	4.5
Physical properties	
Sand (g kg^{-1})	430
Silt (g kg^{-1})	110
Clay (g kg^{-1})	460
Soil texture	Clay

Table 2: Properties of Bambara groundnut shells and the biochar used in the experiment.

Properties	Value
Bambara shells	
Proximate analysis	
HHV (MJ/kg)	19.19
Volatile matter (wt%)	73.83
Ash Content (wt%)	10.10
Fixed Carbon (wt%)	16.08
Ultimate analysis (wt%)	
Carbon	34.63
Hydrogen	11.28
Nitrogen	1.16
Sulfur	1.00
Oxygen[a]	51.93
Biochar	
Ultimate analysis (wt%)	
Carbon	67.20
Hydrogen	4.4
Nitrogen	0.66
Sulfur	0.20
Oxygen[a]	27.54
H/C (atomic ratio)	0.06
O/C (atomic ratio)	0.41
Physio-sorption analysis	
BET surface area (m^2/g)	1.20
Pore volume (cm^3/g)	0.01
Pore diameter (nm)	24.2

[a]By difference.
HHV=Higher heating value
BET=Brunauer–Emmett–Teller

bio-char were determined using ASAP 2020 physio-sorption analyzer (Micromeritics, USA).

Cultural practices

The sweet corn variety used in the experiment was MASMADU obtained from the Malaysian Agricultural Research and Development Institute (MARDI). Prior to sowing, pots measuring 20 cm in height and 15 cm in diameter were obtained and for each, 1 kg of air dried soil was thoroughly mixed with the biochar treatment. Two seeds pot^{-1} were planted at a depth of 2-3 cm using dibbling method and thinned to one plant pot^{-1} at one week after sowing. Weeds from within and around the pots were controlled manually throughout the trial. Nitrogen (N), phosphorus (P) and potassium (K) fertilizers were applied at the rate of 100, 50 and 50 kg N, P_2O_5 and K_2O ha^{-1}, respectively using Urea (46% N), Triple Super Phosphate (46 %P_2O_5) and Muriate of potash (60% K_2O) as nutrient sources. All the fertilizers were applied and mixed thoroughly with the soil before sowing and the computation for both the biochar treatment and fertilizers were based on weight basis of 2 000 000 kg soil ha^{-1}. The research was terminated at 4 weeks after sowing. For each pot, the shoots were severed from the roots using knife and immediately taken to the oven for drying. The oven temperature was maintained at 70^{o}C for 72 hrs.

Data collection and analysis

Data were collected on root length, root volume, root diameter, root dry weight, root surface area, root/shoot ratio, Plant height, number of leaves, leaf area, chlorophyll content, shoot dry weight, total dry weight, ash and nutrients content. The roots were carefully washed, floated on water and scanned using Flatbed Scanner, Epson Expression 11000XL, Seiko, Japan with WinRhizo Pro version 2013 (Regent Instruments, Canada) software. Leaf area was measured using LI-3100C Area Meter, LI-COA® Biosciences. Leaf chlorophyll content was measured using SPAD Chlorophyll Meter, SPAD 502 plus, KONICA MINOLTA, INC. Made in Japan. The ash inorganic composition was determined using energy dispersive x-ray (EDX) (Oxford instrument X-Max 20 mm^2). Elemental compositions were determined using a Perkin Elmer 2400 Series II CHNS/O analyzer (Perkin Elmer SdnBhd, Selangor, Malaysia). The data collected were subjected to analysis of variance procedure (ANOVA) for completely randomized design (CRD) using GenStat® 16th edition. Mean separation was carried out using Tukey's test.

RESULTS

Plant height, number of leaves, leaf area and chlorophyll content

Plant height, number of leaves, leaf area and chlorophyll content of sweet corn as influenced by biochar levels is presented in (Table 3). Significant ($P<0.05$) effect of biochar application on number of leaves plant^{-1}(6-9 leaves) and total leaf area (94.7-273 cm^2) was observed in the experiment. Application of 10 t ha^{-1} biochar recorded 9 leaves plant^{-1}which was higher than 6 and 7 leaves plant^{-1}, respectively recorded in the treatments where 0 and 5tha^{-1} of biochar were applied. Further increase in biochar application to 15-20 t ha^{-1} recorded 8 leaves plant^{-1}which was not significantly different from 7 and 9 leaves plant^{-1} recorded in the treatments applied 5 and 10 t ha^{-1}, respectively. Application of 5 t ha^{-1} biochar recorded total leaf area of 135 cm^2 plant^{-1} which was similar to 95 cm^2 plant^{-1} recorded in the treatments where no biochar was applied. Further increase in biochar application to 10 t ha^{-1}increased the total leaf area to 225 cm^2 and was higher than 95 cm^2 plant^{-1} recorded by the treatments where no biochar was applied but similar to 135 cm^2 recorded where 5 t ha^{-1} of biochar was applied. Application of 15 and 20 t ha^{-1} of biochar recorded total leaf area of 262-273 cm^2 plant^{-1} which was not significantly different from 225 cm^2 recorded in the treatments which received biochar application of 10 t ha^{-1}. Thus, application of 10 t ha^{-1} was optimum for both the number of leaves and total leaf area plant^{-1}.However, despite the differences in the number of leaves and total leaf area plant^{-1} as a result of biochar application, the plant height which ranged from 15-20 cm and chlorophyll content (23.2-27.5) of the crop were not influenced by biochar application.

Root dry weight, shoot dry weight, total dry weight and root/shoot ratio

Root dry weight, shoot dry weight, total dry weight and root/shoot ratio of sweet corn as influenced by biochar levels is presented in (Table 4). Significant ($P<0.05$) effect of biochar application on the root (0.24-0.43 g plant^{-1}), shoot (0.36-0.85 g plant^{-1}) and total dry weight (0.60-0.125) of the crop was observed in the trial. Application of biochar at 5-10 t ha^{-1} recorded root, shoot and total dry weight of 0.24-0.36, 0.40-0.68 and 0.64-1.04 g plant^{-1}, respectively which were not different from 0.24, 0.36 and 0.60 g plant^{-1} recorded where no biochar was applied. However, increasing the biochar application to 15-20 t ha^{-1} recorded root, shoot and total dry weight of 0.40-0.43, 0.77-0.85 and 1.21-1.25 g plant^{-1}, respectively which were higher than 0.24, 0.36-0.40 and 0.60-0.64 g plant^{-1}, respectively recorded at the application of 0-5 t ha^{-1} but similar to 0.36, 0.68 and 1.04 g respectively recorded at the application of 10 t ha^{-1}.However, despite the differences in the root, shoot and total dry weight of the crop as a result of biochar application, the root/shoot ratio recorded in the trial which ranged from 0.48-0.65 was not influenced by biochar application on the crop.

Root length, volume, diameter and surface area

Root length, volume, diameter and surface area of sweet corn as influenced by biochar levels is presented in (Table 5). Significant ($P<0.05$) effect of biochar application on root length (660-1088 cm) of the crop was observed in the trial. Application of 10 t ha^{-1} recorded root length of 1079 cm which was significantly higher than the

Table 3: Plant height, number of leaves, leaf area and chlorophyll content of sweet corn as influenced by Bambara groundnut shell biochar application at the University of Nottingham Malaysia Campus.

Biochar ($t\ ha^{-1}$)	Plant height (cm)	Number of leaves $plant^{-1}$	Leaf area (cm^2)	Chlorophyll content (SPAD)
0	15	6c	95c	23.2
5	16	7bc	135bc	24.6
10	19	9a	225ab	26.3
15	20	8ab	273a	27.5
20	19	8ab	262a	24.9
SEM	1.944	0.422	21.92	1.459
P value	0.089	<.001	<.001	0.356

Means in a column followed by same letter(s) are not significantly different at 5 % level using Tukey's test. P values = Probability values, SEM = Standard error of mean.

Table 4: Root dry weight, shoot dry weight, total dry weight and root/shoot ratio of sweet corn as influenced by Bambara groundnut shell biochar application at the University of Nottingham Malaysia Campus.

Biochar ($t\ ha^{-1}$)	Root dry weight ($g\ plant^{-1}$)	Shoot dry weight ($g\ plant^{-1}$)	Total dry weight ($g\ plant^{-1}$)	Root/shoot ratio
0	0.24b	0.36b	0.60b	0.65
5	0.24b	0.40b	0.64b	0.64
10	0.36ab	0.68ab	1.04ab	0.56
15	0.43a	0.77a	1.21a	0.57
20	0.40a	0.85a	1.25a	0.48
SEM	0.034	0.079	0.108	0.062
P value	0.005	0.004	0.004	0.337

Means in a column followed by same letter(s) are not significantly different at 5 % level using Tukey's test. P values = Probability values, SEM = Standard error of mean.

Table 5: Root length, volume, diameter and surface area of sweet corn as influenced by Bambara groundnut shell biochar application at the University of Nottingham Malaysia Campus.

Biochar ($t\ ha^{-1}$)	Root length (cm)	Root volume (cm^3)	Root diameter (mm)	Root surface area (cm^2)
0	660b	2.27b	0.64	135.4b
5	824ab	2.22b	0.59	151.3b
10	1079a	3.76ab	0.66	225.2a
15	1081a	4.40a	0.72	243.4a
20	1088a	4.24a	0.71	239.8a
SEM	67.1	0.398	0.049	15.42
P value	0.003	0.006	0.342	0.001

Means in a column followed by same letter(s) are not significantly different at 5 % level using Tukey's test. P values = Probability values, SEM = Standard error of mean.

660 cm recorded in the treatments were no biochar was applied but similar to 824 cm recorded at the application of 5 t ha^{-1} biochar. Similarly, application of 15-20 t ha^{-1} recorded root length of 1081-1088 cm which was not significantly ($P>0.05$) different from 824 and 1079 cm recorded at the application 5 and 10 t ha^{-1} respectively. Thus, the root length appeared to be maximized at the application of 5 t ha^{-1}. Significant ($P<0.05$) effect of biochar application on root volume (2.22-4.40 cm^3) of the crop was observed in the trial. Application 5 and 10 t ha^{-1} recorded 2.22 and 3.76 cm^3 respectively which were not significantly different from 2.27 cm^3 recorded where no biochar was applied. Similarly, application of 40-60 kg t ha^{-1} recorded root volume of 4.40-424 cm^3 which was higher than 2.22-2.27 recorded where 0-5 t ha^{-1} was applied but similar to 3.76 cm^3 recorded at the application

Table 6: Ash content of sweet corn as influenced by Bambara groundnut shell biochar application at the University of Nottingham Malaysia Campus.

Biochar ($t\ ha^{-1}$)	Root ash content ($g\ plant^{-1}$)	Shoot ash content ($g\ plant^{-1}$)	Total ash content ($g\ plant^{-1}$)	% ash (whole plant)
0	0.03	0.07b	0.10b	16.0
5	0.03	0.07b	0.10b	15.0
10	0.05	0.13ab	0.17ab	16.3
15	0.05	0.15a	0.20a	16.8
20	0.06	0.17a	0.22a	17.9
SEM	0.007	0.017	0.021	0.763
P value	0.131	0.003	0.004	0.175

Means in a column followed by same letter(s) are not significantly different at 5 % level using Tukey's test. P values = Probability values, SEM = Standard error of mean.

Table 7: Shoot nutrients uptake of sweet corn as influenced by Bambara groundnut shell biochar application at the University of Nottingham Malaysia Campus.

Biochar ($t\ ha^{-1}$)	Calcium ($mg\ plant^{-1}$)	Potassium ($mg\ plant^{-1}$)	Magnesium ($mg\ plant^{-1}$)	Phosphorus (mg plant)
0	2.02	12.4b	0.44	0.26b
5	1.76	14.6b	0.52	0.34b
10	3.70	21.9ab	1.20	0.77ab
15	3.03	30.7a	1.04	1.19a
20	2.78	29.9a	1.06	1.22a
SEM	0.591	2.95	0.424	0.213
P value	0.214	0.003	0.320	0.024

Means in a column followed by same letter(s) are not significantly different at 5 % level using Tukey's test. P values = Probability values, SEM = Standard error of mean.

of 10 $t\ ha^{-1}$. Thus, application of 10 $t\ ha^{-1}$ maximized the root volume of the crop. Significant ($P<0.05$) effect of biochar application on root surface area of the crop was observed in the trial. The root surface area of the crop ranged from 135-243 cm^2 and was higher (225-243 cm^2) in the treatments applied 10-20 $t\ ha^{-1}$ than 0-5 $t\ ha^{-1}$ (135-151 cm^2).However, despite the differences observed in the root length, volume and surface area as a result of biochar application, the root diameter of the crop which ranged from 0.59-0.72 mm was not significantly influenced by biochar application on the crop.

Ash content

Root ash, shoot ash, total ash and percentage ash content of sweet corn as influenced by biochar levels is presented in (Table 6). Significant ($P<0.05$) effect of biochar application on the shoot and total ash content of the crop was observed in the experiment. The shoot and total ash content of the crop ranged from 0.07-0.17 g $plant^{-1}$ and 0.10-0.22 g $plant^{-1}$, respectively. Application of 10 $t\ ha^{-1}$biochar recorded shoot and total plant ash content of 0.13 and 0.17 g $plant^{-1}$, respectively which were similar to 0.07 and 0.10 g $plant^{-1}$ respectively recorded by the application of 0-5 $t\ ha^{-1}$on the crop. Further increase in biochar application to 15 $t\ ha^{-1}$ increased the shoot and total ash content to 0.15 and 0.20 g $plant^{-1}$ respectively, and were higher than 0.07 and 0.10 g $plant^{-1}$respectively recorded by the application of 0-5 $t\ ha^{-1}$ but similar to 0.13 and 0.17 respectively recorded by the application of 10 $t\ ha^{-1}$. Increasing the biochar application to 20 $t\ ha^{-1}$ recorded shoot and total plant ash content of 0.17 and 0.22 g $plant^{-1}$ which were similar to the shoot and ash contents recorded by the application of 10 and 15 $t\ ha^{-1}$ but higher than 0-5 $t\ ha^{-1}$. Thus, application of 10 $t\ ha^{-1}$ could be said to optimize the ash content of the crop. However, despite the difference in the shoot and total ash content of the crop as a result of biochar application, the root ash content (0.03-0.06 g $plant^{-1}$) and the % plant ash content (16.0-17.9 %) were not influenced by the application of biochar.

Nutrients uptake

The shoot nutrients uptake of the crop as influenced by Bambara groundnut shell biochar application is presented in (Table 7). Significant ($P<0.05$) effect of biochar application on P and K content of the crop was observed in the trial. The P and K content of the crop ranged from 0.26-1.22 mg plant^{-1} and 12.4-30.7 mg plant^{-1}, respectively. Application of 10 t ha^{-1}biochar recorded P and K content of0.77 and 21.9 mg plant^{-1}, respectively and were similar to 0.26-0.34and 12.4-14.6 mg plant^{-1}, respectively recorded at the application of 0 and 5 t ha^{-1}biochar. Further increase in biochar application to15-20 t ha^{-1} recorded P and K content of 1.19-1.22 and 29.9-30.7 mg plant^{-1}, respectively which was higher than the values recorded at the application of 0-5 t ha^{-1} but statistically similar to that recorded by the application 10 t ha^{-1}. Thus, application of 10 t ha^{-1} biochar appeared to be optimum for the nutrients uptake of the crop. However, despite the increase in the P and K uptake of the crop as a result of biochar application, the calcium and magnesium uptake of the crop which ranged from 1.76-3.70 mg and 0.44-1.20 mg plant^{-1}, respectively were not influenced by biochar application on the crop.

DISCUSSION

The present investigation revealed the benefit of using biochar from Bambara groundnut shells in growing sweet corn. The positive response of the crop to biochar application could be attributed to the role of biochar in improving soil physical conditions as well as absorbing and retaining soil nutrients for easy access by the crop. This was earlier confirmed by Lehmann et al. (2003) and Barrow, (2012). The higher number of leaves and leaf area recorded in the treatments where biochar was applied could be attributed to the role of biochar in promoting the soil physical properties and soil nutrients retention for uptake by the crop. The higher root, shoot and total dry weight recorded in the treatments applied with biochar could be attributed to its role in improving soil physical properties which provides better conditions for plant growth and to the higher leaf area and number of leaves recorded in the biochar applied treatments. Lehmann et al. (2003) reported biochar addition to increase plant growth and nutrition and attributed it to the increased nutrients availability and reduced leaching of N in the biochar applied treatments. The higher root length, volume and surface area recorded in the biochar applied plot could be attributed to the improved soil conditions around the rooting zone of the crop and hence the more exploration of soil volume for moisture and nutrients (Lehmann et al., 2003; Jeffery et al., 2011). The higher P, K and ash content of the crop recorded in the biochar applied treatments could be attributed to the immense role of biochar in mobilizing soil nutrients as well as absorbing any added soil nutrients and making it more readily available for uptake by the crop. Major et al.(2010) attributed improved crop nutrition on high rainfall acidic soils to improved soil pH and base cation retention in the rooting zone. Likewise, Lehmann et al. (2003) reported biochar addition to increase plant N and P concentrations.

Conclusion

The findings of this investigation revealed that Bambara groundnut shell biochar could be used for increased performance of sweet corn. Application of 10 tha^{-1} biochar was optimum for number of leaves, leaf area,root dry weight, shoot dry weight, total dry weight, root volume, root surface area, ash content and nutrients uptake whereas, root length was optimum at the biochar application rate of 5 t ha^{-1}. Other parameters were not influenced by biochar application on the crop. Thus, application of 10 t ha^{-1} was optimum for increased performance of the crop.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this paper.

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