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Growth, yield and metal residues in *Solanum melongena* grown in fly ash amended soils

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Abstract

Fly ash from Chandrapura Thermal Power Station, Bokaro, Jharkhand (India) was used for amending soil at levels 0, 60, 120, 180 and 240 tons ha^{-1} in which, brinjal (*Solanum melongena*) was grown and elemental residues of amended soil and plant parts were enumerated. Fly ash amendments caused significant improvement in soil quality, water holding capacity (52.64-65.76), pH (6.45-7.05), composition of photosynthetic pigment (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid) and few growth parameters (fresh weight, root length, shoot length) of brinjal with the increase in fly ash amendments. Fruit (edible part) of plants grown in fly ash amended soils had metal residues (mg kg^{-1}) like Cr (0.80-1.16), Co (0.34-1.46), Ni (0.85-1.00), Zn (24.41-32.33), Cu (10.61-15.49), and Mo (0.49-1.46) within the permissible limits. Results indicate that soil amended with fly ash at 180 tons ha $^{-1}$, not only improved the physical properties of the soil but also contributed to the better growth and yield of brinjal.

Key words

Soil, Metal residue, Thermal power station, Fly ash, *Solanum melongena*

Introduction

Although renewable energy sources are gaining increasing attention, coal will continue to play a major role in meeting the global demand for energy. In India, a major part of the total energy requirement is met through coal, and this contribution is likely to continue long into the future in view of the enormous coal reserves in India and the country's steadily growing economy. Combustion of different ranks of coal for generation of electricity in thermal power plant produces coal combustion residues (CCR). Components of these CCR include fly ash, bottom ash, boiler slag and the flue gas desulphurization materials (Haynes, 2009). CCR produced from thermal power plants contain bottom ash in the range from 30 - 35% of burnet coal (Marrero *et al.*, 2007) and fly ash about 70-75% (Haynes, 2009). Fly ash consists of small particles of mineral residues which carried up and out of the boiler in the flow of exhaust gases. Since wide scale coal firing for power generation began in the 1920, millions of tonnes of fly ash and related products have been produced worldwide. Today 52 % of the capacity for generation of electricity in USA alone is from coal and consumption of coal worldwide is projected to increase 36 % between 2000 and 2020 (Jala and Goyal, 2006).

An estimated 550 million tons per year of fly ash is produced through coal combustion in thermal power plants around the world. China, United States, India, Europe, South Africa, Australia, Greece, Japan and Italy have the highest rates of fly ash production (Koukouzas *et al.*, 2005; Yoshiaki *et al.*, 2005; Yunusa *et al.*, 2006; Skodras *et al.*, 2007). In India, coal is the most extensively used and important source of energy, and will probably continue to be so. Fly ash production, in India, was 112 million tonnes in 2005–06 and expected to reach about 150–170 million tones per year by end of 2012 (MoEF, 2007). This much amount of fly ash needs enough land to be disposed off. In dry disposal technique fly ash is being dumped in landfills or basins.

Ash ponds (wet disposal) contain disposed fly ash in the form of slurry. Both methods effectively lead to dumping of the fly ash in landfills on open land (Haynes, 2009). Only for wet disposal of ash it will be required about 82,200 ha of land by the year 2020 at an estimated 0.6 ha per MW (Senapati, 2011).

Efforts have gained momentum to utilize fly ash and India can be accounted to utilize its fly ash in the range of 15% (Jala and Goyal 2006) or higher 30 % (Asokan *et al.*, 2005). A relatively much more optimistic estimate of 41% has been given by Ram *et al.* (2008). Developed countries, however, claim for larger utilization of fly ash for example 85 % in Germany,73 % in Denmark, 60 % in France and UK, 50 % in Poland, 32 % in USA, and 25 % in China (Jala and Goyal, 2006). In India, various options have been adopted for its bulk utilization in areas like manufacturing of cements, concrete, bricks, wood substitute products, stabilization of soil, road base/embankments and consolidation of ground, land reclamation and as a soil amendment in agriculture (Asokan *et al*., 2005; Jala and Goyal, 2006, Tripathi *et al*., 2009; Senapati, 2011).

By virtue of its physical and chemical properties, fly ash is being considered or its application in agriculture. The hollow spheres of fly ash replace larger soil particles and make it possible for small silt particles to accumulate in voids, thus modifying the texture and pore structure of the soil (Truter *et al.*, 2005; Ram *et al.*, 2007b). Chemically, being the source of elements like K, Ca, Mg, S, P, Fe, Mn, Zn, Cu, Co, Mo and B with the exception of N (Jala and Goyal, 2006) fly ash ameliorates the soil by enriching it in mineral availability (Pandey and Singh, 2010). Several studies have been carried out on crops and vegetables grown in fly ash amended soil in different proportions with appreciable results (Basu *et al.,* 2007; Dwivedi *et al.,* 2007; Singh *et al.*, 2008; Tripathi *et al.,* 2009; Gupta *et al.,* 2010). Apart from these positive effects release of trace metals especially boron (Aitken and Bell, 1985) and soluble salts from fly-ash could be a major limitation to its application (Ram *et al.*, 2010). In this context, present study was conducted to examine the optimum fly ash amendment in soil to achieve high growth in brinjal and accumulation of metal residues in its edible part.

Materials and Methods

Collection of fly ash, soil and seeds: Fly ash samples were randomly collected in large plastics bags from dumping sites of 750MW Chandrapura Thermal Power Station (23^{o}75' N and 86^{o}7' E) of DVC in the Bokaro district of Jharkhand state (Fig. 1), India and brought to the laboratory at Central Institute of Mining and Fuel Resource (CIMFR), Dhanbad. Soil samples of top 15 cm layer were collected from fallow land near fly ash dumping site for amendment and control

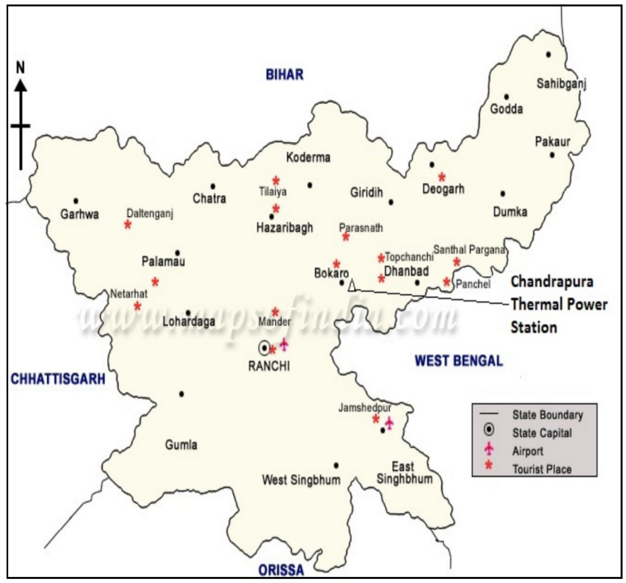

Fig. 1 : Location of study area, Chandrapura Thermal Power station, Jharkhand, India

purpose. The fly ash and soil were sun dried for 5 days and passed through 2 mm sieve before making various amendments (manually). Certified seeds of *Solanum melongena* L. (Swarn Pratibha) a perennial plant of Solanaceae family which can be grown as an annual, were obtained from Birsha Agricultural University, Ranchi, Jharkhand. Crops were harvested between 100-120 days for metal accumulation study.

Experimental design : All the seeds were sterilized with 0.1% mercuric chloride for 5 min to avoid fungal contamination and washed with distilled water for three times and soaked in water for 5 hr. The soaked seed were evenly sown in earthen pot (10 inc in diameter), filled with 7 kg of amendments (four number) and one control (soil) in triplicates. For preparing amendments, equivalent weight of 1 sq m of top soil (up to 15 cm) has been mixed with equivalent weight of fly ash in the increments of 5% to prepare to prepare four amendments with the ratio of 5, 10, 15 and 20% fly ash in soil. Percentage values correspond to 60, 120, 180, and 240 tons ha^{-1} along with one set of control (soil). Prepared seeds were sown in each pot to a depth of 0.5 cm, kept in natural condition, and watered daily till seed germination. The plants were irrigated with tap water at regular interval (300 ml) avoiding leakage of water from the pots and measured root and shoot length respectively.

Physico-chemical analysis of amendments and soil : Physico-chemical analysis was carried out in triplicate on soil and their different amendments with fly ash before the growth of *Solanum melongena* L. Moisture content of soil and fly ash was calculated as the difference of fresh weight of the soil and dry weight of the soil divided by dry weight and multiplied by 100. The pH of different amendment was measured in 1 : 2.5 soil water suspension using pH meter (Consort C831), electrical conductivity (EC) was expressed in µs cm^{-1} of soil and amendments samples was determined following 30 min equilibrium in mechanical shaker a digital conductivity meter (Consort C831).

Organic carbon values of 5 days for old soil and amended samples were determined by oxidation with potassium dichromate in acid medium (Walkley and Black 1934), two lots of 0.5 gm of air dried and sieved soil/ fly ash samples, aliquots of 10 ml of 1 N $K_2Cr_2O_7$ solution, 20 ml of 12N H_2SO_4 and 1.25% $AgSO_4$ were added with constant stirring. After incubation for 30 min to each sample volume of 200 ml distilled water added followed by addition of 10 ml phosphoric acid (85%) 1 ml (0.42 %). The indicator phenyl amine and titrated against 1N ferrous ammonium sulphate. Total concentrations of metals including Zn, Cu, Cr, Ni, Co and Mo were determined in triplicate, using the Open acid digestion method detailed by Roy *et al.* (2007). The samples were analyzed using ICP-MS (Perkin Elmer Sciex, ELAN DRC II).

Plant growth, photosynthetic pigments, yield and chemical analysis of leaves : Plant from one replicate were removed at 40 DAT leaving one plant per pot to avoid resource crunch. Plant individuals were removed by carefully digging (20 cm) in the pots to avoid root damage. Measurement of root and shoot length were taken at the age of 40 and 100 days after germination. Leaves of plants 40 and 100 days after germination were used for estimation of photosynthetic pigments (Chlorophyll a, Chlorophyll b, Total Chlorophyll and Carotenoid) following the method of Arnon (1949). 0.1 gm of (fresh weight) of leaves (Three replicates) samples were crushed with 10 ml of 80 % acetone v/v. After centrifugation at 10000 rpm for 10 min, optical densities of acetone soluble pigments were determined at 643 and 645, 480 and 510 nm. Yield was estimated by detaching and immediately weighing fresh edible part with the help of physical balance. Total concentrations of metal in plant parts were determined with nitric : perchloric acid (3:1) digestion method (Wiermans and Ven Goor, 1986) using ICP-MS (Perkin Elmer Sciex ELAN DRC II).

Statistical analysis : A one way ANOVA in complete randomized block design was used to confirm the validity of data. Comparison from control and between the means of treatment was done by Duncan's multiple range tests (DMRT) (Gomez and Gomez, 1984) using with SPSS - 16.

Results and Discussion

The water holding capacity and moisture content showed an increasing trend from control to progressively increasing amendment and varied from 2.85-4.43%. Bulk density of control and amendments more or less remained in the same range; moreover fly ash had a low bulk density, high surface area and light texture (Asokan *et al.*, 2005; Jala and Goyal, 2006). Addition of fly ash increased the pH of amendments from 6.15 to 7.05. It is may be due to the alkaline pH of fly ash, contributed by the presence of Ca, Na, Mg and OH along with other trace metals (Singh *et al.*, 2008; Chaudhary *et al.*, 2011). Electrical conductivity value (55.47-73.46 µS cm^{-1}) were almost doubled at the level of 240 metric tons fly ash. Rautaray *et al.* (2003) reported that fly ash improves the physical properties and nutrient status of the soil. The values of organic carbon (0.75-0.86%) and organic matter (1.30-1.47%) increased with the addition of fly ash and were more than the normal soil (ICAR, 1996). The application of graded levels of fly ash resulted in an increase in available macro and micro nutrient (P, K, Cr, Co, Ni, Zn, Cu and Mo) in the soil whereas decreased the concentration of nitrogen (Table 1).

The plants grown in soil accumulated appreciable amount of metals in their edible part. The concentration of metal in plant increased proportionally with the concentration of fly ash in different treatments as compared to soil. However, the accumulation of metals, except Zn, in edible part does not always follow the trend of change in metal concentration in the parent material at each treatment. This shows selective uptake of metals and accumulation in edible part. Zinc is the only exception with highest concentration in edible part as well as soil or amended material. Accumulation of Cu was found just second to Zn in all treatments (Table 2). Selective uptake and bioavailability of different metals may be responsible for this variation. The most discussed factors influencing the bioavailability of metals in soil are pH, CEC, clay content and organic matter content (Greger, 2004). The plants growing in fly ash amended soil showed metal accumulation in the following order: Zn>Cu>Ni>Co>Cr>Mo while that growing in 180 t ha^{-1} treatment showed metal accumulation in the following order: Zn>Cu>Mo>Co>Ni>Cr, respectively. Although the plants grown in fly ash accumulated significant amounts of these metals, however vigor of plant was not affected. The accumulation of toxic metals like Cr and Ni was considerably low in 120 and 180 t ha^{-1} amendments including control soil indicating safe utilization for human consumption, moreover relatively high accumulation of essential metals like Zn and Cu may be beneficial for consumption. The amount of Cr and Ni in edible part of *Vigna radiata* grown in fly ash amended soil was relatively very low and may be suitable for consumption. Similar findings have been reported by Chaudhary *et al.* (2011) in V. *radiata* grown in fly ash amended soil .

Table 1 : Physico-chemical characteristic of control and fly ash amended soil of Chandrapura Thermal Power, Jharkhand, India

Parameters	Control soil	Amended soil			
		60 t ha^{-1}	120 t ha^{-1}	180 t ha^{-1}	240 t ha^{-1}
Water holding capacity (%)	42.11^{d} ±0.55	52.64^{d} ± 0.04	63.15^{c}± 0.04	65.70^{b} ± 0.02	65.76^{a} ± 0.02
Moisture content (%)	2.85^{b} ± 0.15	2.58^{b} ± 0.26	3.94^{a} ± 0.20	4.43^{a} ± 0.20	3.76^{a} ± 0.11
Specific gravity (g cm^{-3})	1.21^{b} ± 0.02	1.17^{c} ± 0.02	1.31^{b} ± 0.01	1.43^{a} ± 0.04	1.10^{c} ± 0.03
Bulk density (g cm^{-3})	1.24^{a} ±0.01	1.22^{a} ±0.02	1.24^{a} ±0.01	1.28^{a}±0.04	1.24^{a}±0.03
pH	6.15^{d} ±0.10	6.45^{d} ±0.15	6.70^{c} ±0.23	6.95^{b} ±0.25	7.05^{a} ±0.30
EC(µS cm^{-1})	55.47^{d} ±0.12	56.79^{d} ±0.04	60.65^{c} ±0.02	62.04^{b} ±0.04	73.46^{a} ±0.01
OC(%)	0.75^{c} ±0.02	0.83^{c} ±0.02	0.89^{a} ±0.03	0.90^{a} ±0.01	0.86^{b} ±0.02
OM(%)	1.30 ^{b}±0.02	1.43^{c} ±0.02	1.53^{a} ±0.03	1.57^{a} ±0.01	1.47^{b} ±0.02
Ca(mg kg^{-1})	2.77 ^{d}±0.01	6.74^{d} ±0.02	7.18^{c} ±0.01	8.20^{b} ±0.01	9.15^{a} ±0.02
Mg(mg kg^{-1})	17.70^{c} ±0.02	16.42^{d} ±0.02	17.38^{c} ±0.01	19.87^{b} ±0.01	20.25^{a} ±0.02
N(kg ha^{-1})	296.94^{a}±25.76	290.66 ^{a}±37.83	242.62^{c}±21.04	232.77^{d}±32.17	181.63^{d} ±15.87
P(kg ha^{-1})	9.63^{d} ±0.15	9.67^{d} ±0.02	10.35^{c}±0.02	11.09^{a} ±0.02	10.59^{b} ±0.02
K(kg ha^{-1})	111.60^{a} ±1.99	111.16^{d} ±0.22	111.44^{c} ±0.23	112.22^{a} ±0.11	111.44^{c}±0.14
Metals (mg kg^{-1})					
Cr	79.36^{c}±1.99	108.76^{c}±1.96	128.32^{a} ±1.00	114.6^{b} ±0.86	136.51^{a}±1.15
Co	11.16^{c}±0.32	13.64^{c} ±0.02	17.12^{a} ±0.02	17.04^{a} ±0.02	12.53^{b} ±0.01
Ni	25.59^{c} ±3.32	34.96^{c} ±5.85	43.44^{b} ±10.88	47.28^{a}±11.66	36.91^{c}±11.19
Cu	51.28^{b} ±0.66	79.58^{b}±2.51	62.64^{a} ±2.10	67.25^{a} ±2.30	9.83^{c} ±2.30
Zn	482±6.92^{b}	601.42^{a}±6.90	454.22^{b} ±2.51	477^{a} ±3.05	344.13^{b}±3.02
Mo	36.8^{b} ±2.66	35.08^{c} ±2.51	37.71^{b} ±2.10	25.99^{c} ±2.10	27.91^{c} ±1.19

Values are mean of three replicates ± SD. Significant at $p < 0.05$, different superscripts denote significant differences ($p < 0.05$) between means in a column for each parameter

Table 2 : Accumulation of metals (mg kg^{-1}) in brinjal grown in control and fly ash amended soil

Metals	Control soil	Amended soil			
		60 t ha^{-1}	120 t ha^{-1}	180 t ha^{-1}	240 t ha^{-1}
Cr	1.18^{a} ±0.36	0.80^{c} ±0.06	0.96^{b} ±0.05	1.16^{a} ±0.07	1.02^{b} ±0.02
Co	1.34^{a}±0.02	0.48^{d} ±0.02	0.68^{c} ±0.02	1.46^{a} ±0.02	0.34^{d}± 0.02
Ni	1.55^{a} ±0.01	1.30^{a} ±0.03	0.85^{b} ±0.06	1.30^{a} ±0.01	1.14^{c} ±0.02
Cu	13.30$_{b}$ ±2.53	10.61^{d} ±2.01	13.49^{b} ±2.00	15.49^{a} ±2.01	10.95^{c} ±2.01
Zn	27.62^{a} ±2.01	24.41^{b} ±2.01	31.68^{a} ±3.06	32.33^{a} ±2.01	26.02^{b} ±2.01
Mo	0.85^{b} ± 0.02	0.92^{b} ± 0.01	0.49^{b} ±0.14	1.46^{a} ±0.53	1.15 ^{a} ±0.01

Values are mean of three replicates ± SD. Significant at $p < 0.05$, different superscripts denote significant differences ($p < 0.05$) between means in a column for each parameter

Table 3 : Effect of control and fly ash amended soil on shoot length, root length and yield of brinjal

Fly ash ammendments	40 days	100 days	40 days	100 days	Yield of edible part (g plant^{-1} f.wt.)
	Shoot length (inch)		Root length (inch)		
Control soil	2.60^{b}±0.10	25.17^{b}±0.50	3.80^{b}±0.13	5.70^{b}±0.20	347.65^{b}±20.46
60 t ha^{-1}	2.82^{b}±0.12	30.25^{b}±0.75	4.58^{a}±0.01	6.87^{b}±0.01	384.50^{b}±24.74
120 t ha^{-1}	3.35^{a}±0.15	31.65^{a}±0.65	6.22^{a}±0.04	9.34^{a}±0.18	517.94^{a}±4.80
180 t ha^{-1}	3.27^{a}b±0.01	36.33^{a}±1.00	7.34^{a}±0.12	11.01^{a}±0.10	1006.23^{a}±22.23
240 t ha^{-1}	2.63^{b}±0.13	34.83^{a}±1.50	5.40^{b}±0.06	8.11^{b}±0.10	789.89^{b}±11.80

Values are mean of three replicates ± SD. Significant at $p < 0.05$, different superscripts denote significant differences ($p < 0.05$) between means in a column for each parameter

Table 4 : Effect of control and fly ash amended soil on pigment content (mg g^{-1} f.wt.) in brinjal

Fly ash ammendments	40 days	100 days	40 days	100 days	40 days	100 days	40 days	100 days
	Chl *a*		Chl *b*		Total Chl		Carotenoid	
Control soil	$1.15^{b}\pm0.01$	$1.16^{b}\pm0.01$	$0.58^{a}\pm0.01$	$0.62^{b}\pm0.03$	$1.73^{b}\pm0.01$	$1.78^{b}\pm0.02$	$0.27^{b}\pm0.01$	$0.55^{b}\pm0.02$
60 t ha^{-1}	$1.28^{b}\pm0.02$	$1.37^{b}\pm0.05$	$0.70^{a}\pm0.02$	$0.73^{a}\pm0.06$	$1.98^{a}\pm0.02$	$2.10^{a}\pm0.01$	$0.34^{b}\pm0.03$	$0.65^{b}\pm0.02$
120 t ha^{-1}	$1.43^{a}\pm0.01$	$1.46^{a}\pm0.01$	$0.73^{a}\pm0.01$	$0.82^{a}\pm0.04$	$2.16^{a}\pm0.01$	$2.28^{a}\pm0.04$	$0.48^{a}\pm0.01$	$0.78^{a}\pm0.05$
180 t ha^{-1}	$1.46^{a}\pm0.01$	$1.68^{a}\pm0.01$	$0.75^{a}\pm0.01$	$0.94^{a}\pm0.04$	$2.20^{a}\pm0.01$	$2.62^{a}\pm0.04$	$0.49^{a}\pm0.01$	$0.92^{a}\pm0.06$
240 t ha^{-1}	$1.39^{b}\pm0.17$	$1.19^{b}\pm0.05$	$0.70^{a}\pm0.01$	$0.65^{b}\pm0.05$	$2.09^{a}\pm0.17$	$1.84^{a}\pm0.05$	$0.38^{b}\pm0.01$	$0.64^{b}\pm0.06$

Values are mean of three replicates ± SD. Significant at $p < 0.05$, different superscripts denote significant differences ($p < 0.05$) between means in a column for each parameter

The data presented in Table 3 and 4 showed that all the plant growth parameters (root length, and fresh weight edible part of brinjal) and photosynthetic pigments were significantly increased in all amendmened soil compared to control set. The plant growth was better in 60, 120, 180, and 240 t ha^{-1} amendments in comparison of control, maximum being at 120-180 t ha^{-1} level of flyash. The photosynthetic pigments (Chl *a,* Chl *b*, total Chl and carotenoid) significantly increased in soil amended with 120 to 180 t ha^{-1} of fly ash as compared to control soil. Kenneth *et al.* (2000) reported similar trend for carotenoid with an explanation that it might be due to a defense mechanism of plant against metal stress. However, carotenoid concentration started decreasing at 20% or 240 tons ha^{-1} amendment. The beneficial effect of fly ash at lower levels have already been reported in soybean, cabbage, chickpea, cucumber, lentil, maize, potato, wheat and tomato *etc*. Chaudhary *et al*. (2011) reported a contrasting trend in *V. radiata* in terms of biomass and shoot length. Yield in terms of fresh weight of edible part was found maximum in 180 tons ha^{-1}amendment. High yield have been achieved in the treatment where highest growth and photosynthetic pigment is accumulated. Fly ash amendment from 5% (Singh *et al*., 2008) to 40% (Singh and Siddiqui, 2003 and Agrawal *et al*., 2004) has been reported to be helpful in agriculture crops for higher yield. The decrease in Chl a, b, total Chl and carotenoid in 240 t ha^{-1} may be ascribed to accumulation of heavy metal in leaves as reported by (Krupa and Baszynski, 1995). There is a possibility that some metals affect chlorophyll mature leaves than younger leaves on treatment. In general, changes in chlorophyll accumulation induced by Cd^{2+}, Cu^{2+} and Hg^{2+} strongly depend on the growth stage of plant treated with the metal (Kurdziel, 2004). Skorzynska-Polit and Baszynski (1995) reported that Cd affected biosynthesis of Chl in mature leaves than in younger, developing leaves.

Among all the treatments, application of fly ash at 120-180 t ha^{-1} levels were found beneficial for the plant growth and fresh weight of edible part in the present study. However, level higher than 180 t ha^{-1} was found to reduce growth and other parameters of brinjal. This study shows that the available nutrients present in fly ash are beneficial if fly ash is mixed at certain levels for a particular plant species. Findings of the study, as similarly reported by Ram and Masto (2010), in terms of growth and fresh weight accumulation indicates the beneficial use of fly ash as an eco-friendly nonconventional fertilizer at 120 and 180 t ha^{-1} levels respectively, and address the problem of land utilization for fly ash disposal.

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