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RESEARCH ARTICLE

MANAGEMENT OF SUB-SOIL SODICITY FOR SUSTAINABLE BANANA PRODUCTION IN SODIC SOIL – AN APPROACH

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ABSTRACT

At present about 20 per cent of the world's irrigated land is salt-affected and 60 per cent of salt-affected soils are sodic. These soils are ameliorated using soluble calcium (Ca^{2+}), which replaces sodium (Na^{+}) at the cation exchange sites of the soil. The displaced Na^{+} is then leached from the root zone through flushing (excess irrigation) a process that requires adequate flows of water through the soil. Also, most of the reclamation activities are being restricted to the top 0-15 cm which lead to development of secondary salinization and decreases the economic productivity of the soils due to reduced bilological activity in the rhizosphere. Therefore, the purpose of this study was to develop sub soil sodicity management technologies for commercial banana cultivation (cv Pisang Awak) under pits in sodic soils having pH 9.0 (surface) to 9.47 (sub-surface) by using biological ameliorants in integration with reduced level of chemical ameliorants and to study the mechanism underlying alleviation of salt stress by the plant. Application of 25 GRgypsum in the pits along with CSR-B-3 strain of Bacillus thurigenesis a native rhizospheric bacteria of sodic soil reclaimed the rhizosphere soils up to 60 cm. Their combination with vermicompost alleviated the salt stress in the rhizosphere of the crop which resulted in higher bunch weight of 22.7 kg /plant due to the integrated approach of bio and chemical ameliorant. The pH, bicarbonate, carbonate and sodium adsorption ratio (SAR) of soil was reduced due to the synergistic activity of ameliorants. The concentration of potassium (K) and other micronutrients increased in the leaves while Na content decreased, resulting in lower Na/K ratio.

INTRODUCTION

Studies on recent trends and future projections, suggested that to produce more food and fibre for the world expanding population, there will be an increased demand for the use of marginal-quality water and land resources (Bouwer, 2000; Gupta and Abrol, 2000). A number of major irrigation schemes throughout the world have suffered problems of sodicity, reducing their agricultural productivity and sustainability. India is also confronting the same problem. (Gupta and Abrol, 2000). Sodic and saline-sodic soils account for about 60 percent of the world's salt- affected area (Tanji, 1990; Szabolcs, 1994). The sodicity induced soil degradation is a major environmental constraint with severe negative impacts on agricultural productivity and sustainability in arid and semi-arid regions. Sodic soils are characterized by excess level of sodium ion (Na^{+}) in the soil solution phase as well as on cation exchange complex, exhibiting unique structural problems as a result of certain physical processes (slaking, swelling, and dispersion of clay) and specific conditions (surfacing, crusting and hardsetting) (Summer, 1993; Qadir and Schubert, 2002). These soils are ameliorated by providing a readily available source of calcium (Ca^{2+}), to replace excess Na^{+} on the cation exchange complex. Chemical amendments such as mineral gypsum have been used extensively so far in the amelioration of these soils upto 0-15 cm (Singh *et al*., 2009). Though the amendments reclaimed the top 0-15 cm of soil, there is no improvement in the pH, physical and biological properties of the sub surface soil > 15 cm depth which makes them unsuitable for commercial agriculture (Damodaran *et al*., 2011). Unfortunately, most of the farmers of sodic lands in developing countries are small and marginal whose food, nutritional and economic security is a big challenge. Therefore, the management of sub-surface sodicity below 15 cm and their bio-physical properties are essentially required with a long duration economic crop which remains in the soil thorough the year and produce sufficient root biomass in the sub-surface. Banana (*Musa* spp.) one of the world's most important fruit crop is grown in more than 120 countries throughout tropical and subtropical regions (Molina and Valmayor, 1999) and is the staple food for more than 400 million people. It was being cultivated for years in the basins of perennial rivers, but due to development of canal system in the command areas the cultivable lands had been changed to sodic soils which had limited the cultivation of this crop (Jeyabaskaran, 2000). Also, there is a need for biological amendments to enhance the biological activity in the rhizosphere zone and also to reclaim the sub-surface. This will require the development and implementation of efficient, inexpensive, and environmentally acceptable management strategies designed to enhance the productivity and biodiversity of these soils (Qadir and Oster, 2002). Therefore, this paper evaluates the different approaches in sodic soil amelioration using eco-friendly organic and biological ameliorants to reclaim surface (0-15 cm) and the sub-surface soil (15 – 45 cm) sodicity and reduce the level of chemical amendments used in reclamation. Also, the current study was aimed to evaluate the efficacy of the amendments in increasing the yield, biomass and nutrient uptake potential of the banana crop.

MATERIALS AND METHODS

Preparation and Soil Application of Gypsum and Posphogypsum

The experimental soil is characterized as Typic Natrustalfs with pH varied from 9.0 at the surface to 9.47 at sub-surface. The Gypsum

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Requirement (GR) of soil was determined according to the methods of U.S. Salinity Laboratory Staff (1954) for each layer of soil (0-15, 15-30, 30-45 and 45-60 cm) besides a cumulative GR for 0-60 cm soil layer by making a composite sample. The calculation was based on the purity percentage of 70% for commercial grade gypsum @ of 50 GR and 25 GR which was @ 2.50 and 1.25 kg of commercial grade gypsum /pit (size 60x60x60cm), respectively. Originally 60 cm depth of soil were dug out from the pits at a spacing of 2 x 2 m and mixed thoroughly and homogenized. The pits were then refilled up to a depth of 30 cm with the homogenized soil. Gypsum was incorporated by mixing them thoroughly in the remaining 30 cm depth.

Field Experiment and Design

This study was carried out in banana crop (cv Pisang Awak) during 2008 to 2011 at the experimental farm of Central Soil Salinity Research Institute Regional Research Station Lucknow, India, located at 260 47´45´´ to 260 48´13´´ N latitude and 800 46´7´´ to 800 46´32´´ E longitude lying in the Central part of Indo-Gangetic plain with an average rainfall of 800 mm. A native strain of *Bacillus thurigenesis* (CSR-B-3; JQ 768235) isolated from sodic soils of pH 9.8 and screened for growth promotion activity in sodic soils was obtained from Microbiology Laboratory, Central Soil Salinity Research Institute, RRS, Lucknow. The suckers of *Pisang awak* were planted in the first week of March and all agricultural practices were followed in this experiment. A loopful of bacterium was inoculated into the nutrient broth and incubated in a rotary shaker at 150 rpm for 48 h at room temperature (28 ± 20C). After 48h of incubation, the broth containing 6 x 10^8 CFU ml^{-1} was used for treatment @ 0.2 % as soil application (Nandakumar *et al.*, 2001) in the root zone of banana crop during initial, 5^{th}, 7^{th} and 9^{th} month of planting in approaches involving biological ameliorant. About 5 kg of vermicompost / plant was used as an approach using organic ameliorant as soil application in the canopy region during initial, 5^{th}, 7^{th} and 9^{th} month of planting of banana crop. The different approaches comprising of:

Approach 1 (A_1) - 50 GR_{Gypsum}
Approach 2 (A_2) - 25 $GR_{Gypsum+}$ mulch
Approach 3 (A_3) - 25 $GR_{Gypsum+}$ mulch + CSR-B-3
Approach 4 (A_4) - 25 $GR_{Gypsum+}$ mulch + vermicompost
Approach 5 (A_5) – 25 $GR_{Gypsum+}$ mulch + vermicompost + CSR-B-3
Approach 6 (A_6) – Control with no amendments, were imposed in each pits (size 60x60x60cm).

The experiment was laid in randomized block design (RBD) with three replications in each treatment. A total of 8 plants were taken in one replication. During shooting (flowering) period of each season, plant height, plant girth, number of leaves/plant and bunch weight were recorded. Total soluble solid (TSS) in the fruits was determined using brix meter after harvest. The soil samples (0-60 cm) were collected from each treatment during pre and post experiment period.

Soil analysis

The soil samples collected were air dried and ground to pass through 2 mm sieve and a saturated extracts of the soil samples were prepared. Various physico-chemical parameters were determined in the extracts by adopting standard methods. The pH of the soil extract was determined potentio-metrically by a ORION ion analyzer (5 star series) using a pH electrode calibrated with a pH buffer of 7.0 and 10.0 pH. Carbonate (CO_3) and bicarbonate (HCO_3) were determined by titrimetic method (acid base titration) (Richards, 1954). Calcium (Ca) and magnesium (Mg) were determined by versenate method (EDTA titration) (Chang and Bray, 1951). Sodium (Na) was determined by flame photometer (Richards, 1954) while sodium adsorption ratio (SAR) was determined by following generic equation:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

Distribution of Na^+ and K^+ in the banana leaf (3^{rd} leaf) was studied by extracting the oven-dried (65°C) samples in 100 mmol m^{-3} acetic acid in a water bath for 2 h at 90°C. The Na^+ and K^+ in the extract were determined using a flame photometer.

Statistical analysis

The data was analyzed using SAS 9.2 version. The pooled data for two years was subjected to significance at P<0.05 using Least Significant Difference (LSD).

RESULTS

Soil pH

High pH of the soil significantly reduced the crop economic parameters like bunch weight, height and girth of the plants. However, the approach based on gypsum application at 50GR and 25GR reduced the soil pH and provided a favourable environment for plant growth (Fig. 1). The decrease of pH was found to be higher in the approaches having 50 % chemical ameliorants (A_1), followed by the combination of biological (CSR-B-3) and organic ameliorants (vermicompost and paddy straw mulch) with 25 GR $_{gypsum}$ (A_5). Addition of chemical ameliorants @ 25GR along with mulch, CSR-B-3 and vermicompost reduced the pH value on par with 50 GR of gypsum application in 0-15 cm depth. The effects of amelioration were more pronounced in A_1, A_3 and A_5 as compared to the other treatments.

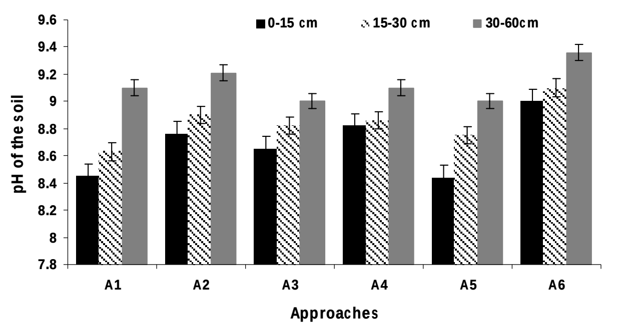

Fig. 1. Effects of various approaches on the pH of the soil in banana

Soil HCO_3, CO_3 and SAR

The effects of ameliorant on chemical characteristics of soils during pre and post experiment as presented in Fig. 2 and Fig 3, revealed a decreased in the concentration of CO_3 and HCO_3 concentration in soil in the post experiment scenario as compared to control (A_6).

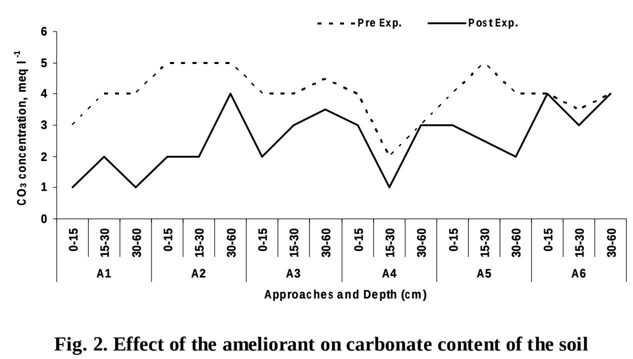

Fig. 2. Effect of the ameliorant on carbonate content of the soil

The approaches with 50 GR_{gypsum} (A_1), 25 GR_{gypsum} + mulch + CSR-B-3 (A_3) and 25 GR_{gypsum} + mulch + vermicompost + CSR-B-3 (A_5) resulted in higher reduction of HCO_3, CO_3 contents than other approaches. The sodium adsorption ratio (SAR) values in the post experiment also showed a reduction in all the approaches at the depths 0-15, 15-30 and 30-60 cm, having pronounced effects in A_1, A_2, A_3

and A_5 particularly at 0-15 cm depth. The decrease in SAR values among approaches involving 25 GR_{gypsum} was found to be higher in CSR-B-3 treated approach.

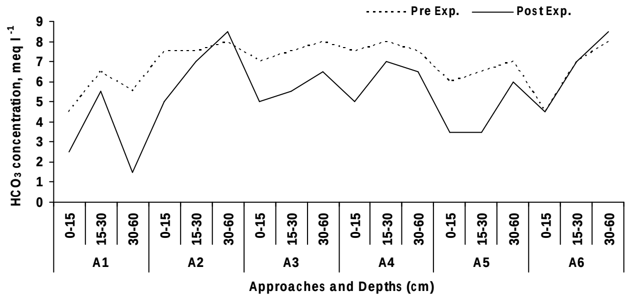

Fig. 3. Effect of the ameliorant on bicarbonate content of the soil

Vegetative and Yield Parameters

The growth and yield parameters of banana in sodic soils and the effects of different approaches on their performance are illustrated in Table 1. It was found that the sodicity significantly reduced the plant height, girth, numbers of leaves, bunch weight and also the total soluble salts (TSS) of the fruit. Gypsum application significantly increased the vegetative and fruit yield of banana compared to control. However, application of CSR-B-3 strain of *Bacillus* with mulch and vermicompost in pit treatments of $25GR_{gypsum}$ significantly increased the plant height (362 cm), plant girth (56.5 cm), number of leaves (12.5) bunch weight (22.7 kg) and TSS (24.1 %) compared with other approaches and untreated control plants. The percent increase of plant height, plant girth, number of leaves, bunch weight and TSS were 57.7%, 94.8%, 38.9%, 908.9% and 43.4%, respectively in A_5 approach with respect to control (A_6). Application of CSR-B-3 with mulch + 25 GR_{gypsum} (A_3) also resulted in significantly higher bunch weight than A_1. A positive and synergistic effect was observed with the application of native strain of *Bacillus* (CSR-B-3) on 25 GR_{gypsum} +mulch (A_3)and 25 GR_{gypsum} +mulch + vermicompost (A_5).

Table 1. Effect of ameliorants on sodium adsorption ratio (SAR) of banana under sodic soils

Approaches	Pre Treatment			Post treatment		
	0-15	15-30	30-60	0-15	15-30	30-60
A1	14.34	15.55	14.52	6.31	8.80	9.00
A2	14.53	18.09	19.88	6.98	16.45	16.62
A3	14.20	17.60	18.71	6.84	8.99	10.91
A4	16.25	14.00	18.80	13.00	10.91	10.80
A5	14.69	16.33	21.83	6.96	8.63	10.35
A6	14.43	19.36	21.43	14.43	19.36	21.43
CD (5%)	0.602	0.572	1.039	0.341	0.338	0.386

A_1(50 GR_{Gypsum}); A_2(25 GR_{Gypsum}+mulch); A_3(25 GR_{Gypsum}+mulch+CSR-B-3); A_4(25 GR_{Gypsum}+mulch+ vermicompost) ; A_5(25 GR_{Gypsum} + mulch + vermicompost + CSR-B-3); A_6 (Control with no amendments)

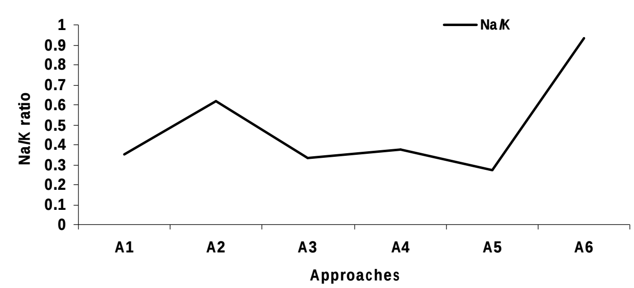

Fig. 4. Effect of different approaches on Na/K ratio of banana leaves

Na/K ratio

The concentration of Na and K in the leaves of banana under different approaches was determined which is presented in Fig. 4 in the form of Na/K ratio in leaves of the plant. The Na/K ratio increased with the increase in sodicity. The Na/K ratio was found to be least in A_5 followed by A_3. It was observed that the yield of banana (bunch weight) increased with the decrease of Na/K ratio. Inoculation with CSR-B-3 with mulch and vermi-compost in pit treatments of $25GR_{gypsum}$ increased the uptake of K and reduced the uptake of Na which resulted in low Na/K ratio.

Table 2. Effect of ameliorants on vegetative and reproductive growth of banana under sodic soil

Approaches	Pl.Height (cm)	Pl.Girth (cm)	No.of leaves	No. of suckers	Bunch wt. (kg)	TSS (%)
A1	335	52.5	11.5	5	17.4	21.5
A2	288	52	11.5	4.5	11	20.2
A3	294	49	10.5	3	20.12	21.2
A4	267	48.5	10	6	11.8	22.4
A5	362	56.5	12.5	7.5	22.7	24.1
A6	229.5	29	9	0	2.25	16.8
CD (5%)	9.53	5.1	1.42	3.6	1.4	5.52

A_1(50 GR_{Gypsum}); A_2(25 GR_{Gypsum}+mulch); A_3(25 GR_{Gypsum}+mulch+CSR-B-3); A_4(25 GR_{Gypsum}+mulch+ vermicompost) ; A_5(25 GR_{Gypsum} + mulch + vermicompost + CSR-B-3); A_6 (Control with no amendments)

Uptake of Micronutrients (Zn, Cu, Fe, Mn)

Uptake of Zn, Cu, Fe and Mn significantly decreased with the increase in sodicity. The uptake of these nutrients was increased with the decrease in pH and SAR. The approaches A_3 and A_5 recorded higher Zn, Cu, Fe and Mn uptake in the leaves as compared to the other treatments and control (Table 3).

Table 3. Effect of treatments on micro-nutrients contents (ppm) of banana leaves at the harvest

Treatment	Na	K	Zn	Cu	Fe	Mn
A1	7.5	21.25	20.4	7.24	410.36	23.4
A2	10.55	17.1	17.2	5.89	316.7	10.2
A3	6.76	20.43	24.66	7.72	517.4	32.55
A4	7.2	19.3	21.4	7.15	398.65	25.22
A5	6.39	23.5	26.87	7.85	586.5	34.54
A6	13.35	14.35	12.59	5.99	218.2	14.29
CD (0.05)	0.628	0.936	1.84	0.489	3.167	3.198

A_1(50 GR_{Gypsum}); A_2(25 GR_{Gypsum}+mulch); A_3(25 GR_{Gypsum}+mulch+CSR-B-3); A_4(25 GR_{Gypsum}+mulch+ vermicompost) ; A_5(25 GR_{Gypsum} + mulch + vermicompost + CSR-B-3); A_6 (Control with no amendments)

DISCUSSION

Sodicity significantly reduced the phenological characters like plant height, girth, number of leaves and bunch weight due to the direct effects of ion toxicity, or indirect effects of saline ions that cause soil/plant osmotic imbalance (Abdel Latef, 2010). A number of other workers have reported similar effects of salinity in reducing fruit yield for a range of other agricultural and horticultural crops including banana (Jeyabhaskaran, 2000), tomato (Al-Karaki, 2000). The chemical amendments (gypsum) reclaimed the soil of the pits upto 60 cm effectively and reduced soil pH and SAR in the approaches. In several comparative studies of soil sodicity, the ameliorative effects of gypsum were initially found to be confined to the zone into which the amendment has been incorporated (Robins, 1986; Qadir and Oster, 2002). Once amelioration approached completion in the zone of incorporation, it progress downwards (Qadir *et al.*, 2006). Inoculation with CSR-B-3 with mulch and vermi-compost in pit treatments of $25GR_{gypsum}$ resulted in significantly higher yield and phonological characters like plant height, girth, number of leaves and TSS and simultaneously reduced the gypsum dosage from 50 GR to 25 GR. Use of rhizospheric bacteria can offer tolerance to the plants and promote their growth as a potential growth promoter (Nowak, 1998).

Treatment with gypsum decreased the pH of the soil considerably. At the end of three years, the pH was reduced from an initial pre-experimental range of 9.09 to 9.38 at 0-60 cm depth to a range of 8.42 to 9.21 over the various approaches. The Gypsum application at 50GR or 25GR with other ameliorants significantly reduced soil HCO_3, CO_3 and SAR over the control treatment. Chemical amendments play a vital role in soil amelioration by providing a source of soluble Ca^{2+} ion in sodic soil and promoting the replacement of Na^+ from the cation exchange complex (Oster, 1982). The amendments commonly used as a direct Ca^{2+} source include calcium chloride ($CaCl_2.2H_2O$), mined gypsum ($CaSO_4.2H_2O$) and phosphogypsum. The SAR values of all the approaches except A_4 and the control A_6 at 0-15 cm depth was found to be less than 13 which are generally taken to be the threshold limit for non sodic soils whereas at a depth of 15-30 cm and 30-60 cm values were more than the threshold value in approaches A2 and A6. The SAR values have been widely used as an approximation of ESP, where values of more than 13 makes the soil dispersive and suffer from serious physical problems when water is applied (Qadir *et al.,* 2006). Plants subjected to ameliorants recorded lower Na/K ratio compared to the control. Even among the treatments, CSR-B-3 native strain of *Bacillus* and vermicompost with 25GR of gypsum recorded lower Na/K ratio in leaves, which attributed to the higher economic yield. It has been reported earlier that an increase in Na/K ratio decreases the yield significantly while an insufficient Potassium (K^+) supply reduces the total dry matter production and drastically affects the bunch weight (Jeyabhaskaran, 2000). The reduction in dry weight is basically caused by inhibition of K+ influx into the cell by Na+ ions (Kronzuker *et al.*, 2006). Besides this, the Na+ stimulated K+ ion release from the tissues of the plant may be another cause for such reduction. (Shabala *et al.,* 2006). These biological ameliorants also reduced HCO_3, CO_3 and SAR contents in the soil with lower level of applied gypsum. This reduction in pH contributed to the increased uptake of K as well as micronutrients like Zn, Mn, Fe and Cu. It has been reported earlier that an increase in Na/K ratio decreases the yield significantly while an insufficient Potassium (K^+) supply reduces the total dry matter production and drastically affects the bunch weight (Jeyabhaskaran, 2000). The endophytes enhance the uptake of nutrients through biological processes (Hanafy-Ahmed *et al*., 1995).

A holistic approach of reclamation must consider the nutrient available status of the soil after amelioration, crop productivity and environmental issues (Qadir *et al.*, 2006). High K accumulation by mycorrhizal plants in saline soils have also been reported previously (Giri *et al.*, 2007), that could be beneficial by maintaining high K/Na ratio In recent decades, a crop-based approach (Phyto-remediation, biological reclamation, or vegetative bioremediation) has received considerable attention in many developing countries, as it is much cheaper than chemical amelioration, the cost of which are prohibitively high (Robbins, 1986; Ilyas *et al.*, 1993; Ghaly, 2002). The decrease of the uptake of Zn, Cu, Fe and Mn with the increase in sodicity could be explained by the fact that at higher pH in sodic soils most of the micronutrients are less available (Page *et al.*, 1990; Naidu and Rengasamy, 1993) because of the lower solubility of these cationic trace elements (Page *et al*., 1990). Therefore, under such conditions, Zn, Cu, Fe and Mn become less available for plant uptake in sodic soils and results in the micronutrient deficiencies. However, with the decrease in pH and SAR, particularly in the approaches A_3 and A_5, increased uptake of these nutrients was recorded. This may be due to the integration of *Bacillus*, mulch (or mulch and vermicompost) with 25 GR_{gypsum} in these approaches. These components might have released some root exudates, acidic in nature and lowered down the pH value of the soil significantly. The lowering of the pH value after acidification of the sodic soil and the release of an appreciable amount of Zn was reported by previous researchers (Naidu and Rengasamy, 1993). Treeby *et al.* (1989) found that root exudates produced by barley increased the concentrations of various micronutrients in the soil. Besides this, the addition of Ca^{2+} from gypsum replaces exchangeable Na^+ at the cation exchange complex of the soil and also lowers the pH value.

Conclusion

The results confirmed that the banana cultivation in sodic soil using pit treatment with 25 GR_{gypsum} followed by soil application of CSR-B-3 strain of *Bacillus* along with vermi-compost and mulch contributed a sustainable and higher yield. The combination of biological and chemical amelioration reduced the dosage of chemical amendment to 50 % and showed significant interactions with nutrient uptake and soil sodicity reduction. The sustainable management of sodicity-induced land degradation represents an excellent opportunity to conserve the environment and provide livelihood for marginal farmers of developing countries in sodic lands.

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