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SPATIAL DISTRIBUTION OF SILICON AVAILABILITY IN THE HIGHLAND PADDY FIELDS OF WEST SUMATERA, INDONESIA

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ABSTRACT

Silica (Si) is a functional element in rice fields that is rarely studied, especially in Solok Regency. Intensive management without a fallow period causes silica to be transported out through high uptake by rice plants. This research aims to determine the distribution of available Si in the highland rice fields in Gunung Talang District, Solok Regency, West Sumatra. The research was carried out using a survey method. Soil samples were taken following the topo-sequence of the area of 600–1,100 meters above the sea level, which consists of 3 groups of rice fields based on height differences, namely the lower, middle, and upper fields. These rice fields have two types of straw management, namely burning and immersing. The research showed that the available Si content was 10.48–293.66 mg/kg_ with an average of 133.34 mg/kg. The available Si content is higher in the upper paddy fields compared to the lower and middle paddy fields. Based on differences in straw management, the available Si content is lower in fields with straw buried compared to burned straw. The application of Si fertilizer is highly recommended to obtain the available Si content in the soil.

Keyword: *highland, paddy fields, Silica (Si), spatial distribution*

ABSTRAK

[DISTRIBUSI SPASIAL KETERSEDIAAN SILIKON PADA TANAH SAWAH DATARAN TINGGI SUMATERA BARAT INDONESIA]. Silikon (Si) merupakan unsur fungsional untuk tanaman padi yang jarang diteliti khususnya di lahan sawah Kabupaten Solok. Pengelolaan yang intensif tanpa adanya masa bera menyebabkan silika terangkut keluar melalui serapan yang tinggi oleh tanaman padi. Penelitian ini bertujuan untuk mengetahui distribusi Si tersedia pada tanah sawah dataran tinggi di Kecamatan Gunung Talang, Kabupaten Solok, Sumatera Barat. Penelitian ini menggunakan metode survei. Sampel tanah diambil mengikuti topo-sekuen daerah tersebut (600-1.100 m.d.p.l) yang terdiri dari 3 kelompok sawah berdasarkan perbedaan ketinggian, yaitu sawah bagian bawah, bagian tengah, dan bagian atas. Kelompok sawah ini memiliki dua pengelolaan jerami yaitu dibakar dan dibenamkan. Hasil penelitian menunjukkan bahwa kandungan Si tersedia sebesar 10,48-293,66 mg/kg dengan rata-rata 133,34 mg/kg. Kandungan Si tersedia lebih tinggi pada lahan sawah bagian atas dibandingkan dengan lahan sawah bagian bawah dan tengah. Berdasarkan perbedaan pengelolaan jerami, kandungan Si tersedia lebih rendah pada lahan dengan pembenaman jerami dibandingkan dengan jerami yang dibakar. Penambahan pupuk mengandung Si sangat dianjurkan untuk meningkatkan kandungan Si tersedia di dalan tanah.

Kata kunci: *dataran tinggi, distribusi spasial, lahan sawah, Silica (Si)*

INTRODUCTION

Rice functions as the primary staple crop within Indonesia, catering to the sustenance needs of its populace. As of 2022, Indonesia boasted a population exceeding 275 million individuals, with rice consumption surpassing 30 million tons, marking a 0.5% increase from the preceding year (Data Indonesia.id, 2023). The population of Indonesia is experiencing a rapid ascent, projected to reach 300 million by 2045, necessitating a commensurate increase in food production (Ulhaq & Wahid, 2022). Substantial endeavors and strategic frameworks are imperative to ensure food security in the forthcoming years. Agricultural intensification stands out as a swift and feasible approach in this endeavor. Various initiatives are being undertaken, including the adoption of responsive and resistant seed varieties, enhanced irrigation techniques, and judicious application of fertilizers and pesticides (Suhardiman *et al*., 2015).

In paddy fields, commonly referred to as Sawah in Indonesian, fertilizer application typically focuses on primary nutrients such as nitrogen (N), phosphorus (P), and potassium (K), often overlooking the importance of nutritional balance within the soil. This practice has raised significant concerns regarding the availability of other essential nutrients and the resultant quality of rice yield. Interestingly, the growth of paddy and the quality of rice are also significantly influenced by additional elements such as silica (Si) (Liu *et al*., 2017; Siregar *et al*., 2020), despite not being classified as an essential plant nutrient. Silica functions as a functional element for rice plants, absorbed by the plant roots in the form of monosilicic acid (H_4SiO_4) (Epstein, 1999). Its role includes maintaining the structural integrity of leaves, promoting upright orientation, and enhancing sunlight absorption efficiency (Makarim *et al*., 2007), indirectly impacting rice productivity. Despite the typically high presence of silica in soils, intensive management practices without a fallow period have led to significant silica depletion, primarily due to the high silica uptake by rice plants. Estimates suggest that rice production, at 5 tons/ha, can deplete soil silica by as much as 230-470 kg/ha (Dobermann & Fairhurst, 2000; Husnain *et al*., 2012). Additionally, farmers often neglect to return paddy residues such as straw or husk to the field, despite their silica content. Darmawan *et al*. (2006) reported a notable decline in available silica content in rice fields across Java Island, decreasing by approximately 11-20% over the last three decades. This issue poses a significant challenge for the sustainable development of rice cultivation in Indonesia.

Sawah has been important for the people in West Sumatra, not only for the food production but also culturally crucial as its part of the family property. One of the popular areas of rice production in this province is Gunung Talang Sub-district, Solok Regency, which is known as “Bareh Solok, means Solok Rice. Paddy fields in this area are spread out from an altitude of ±500 - ±1100 m.a.s.l with water sources coming from permanent and temporary irrigation canals. According to Jamulya & Haryono (2000) topography/relief are one of the soil forming factors, in hilly areas the weathering and leaching process generally occurs more quickly because drainage is better than in flat areas. This condition has led to differences in the formation of nutrient availability and the influence of land management which is not the same in various locations. In this area, rice is normally cultivated for 2-3 times a year. The use of N-P-K fertilizers every planting period is common and some of the farmers were directly burning the straw after harvest to cut the land preparation time. However, some others were practicing a different approach by buried the straw into the ground. Since paddy absorbed high amount of Si, the returning back the straw to the field may improve the Si availability. Nevertheless, no information about Si status in this area is available. In this study, we aimed to determine the distribution of Si available in highland paddy fields in Gunung Talang Sub-District, Solok Regency, West Sumatera.

MATERIALS AND METHODS

Study site and sampling method

The study site was located on a foot slope of Mount Talang (coordinates: 0◦52’30” - 0◦57’0”S and 100◦36’30” - 100◦40’30”E; elevation: 600 – 1100 m.a.s.l, area: 1525.26 ha) an active volcano in West Sumatra, Indonesia (Figure 1). The study site encompasses several villages (Nagari), namely Nagari Talang, Nagari Jawi Jawi Guguak, Nagari Koto Gaek Guguak, Nagari Koto Gadang Guguak, Nagari Sungai Janiah, and Nagari Cupak. The mean temperature is 18°C, and the mean annual rainfall is 2519 mm. This area is primarily composed of Andisol, classified according to Soil Taxonomy (2014), and has been extensively utilized for rice cultivation. In some areas (at 850 - 1100 m.a.s.l), rice cultivation is rotated with sweet potatoes, and macro fertilizers such as Urea, TSP, and Phonska (NPK) are used as additional nutrients without the addition of micronutrients or silicon fertilizers. The planting period occurs 2-3 times a year, with rice straw being burned and buried in several places to expedite land preparation.

Soil samplings

Soil samples were taken following the toposequence of the area. The altitude is range from 600-1100 meters above sea level (m.a.s.l.) with intervals of 50 m. The bulk samples were collected at 0-20 cm soil depth with a total of 40 sample points consisting of 3 groups of rice fields based on the differences elevation, i) lower rice fields at 600-750 m.a.s.l. with a total of 16 sample points, ii) middle rice fields at 750-850 m.a.s.l. with a total of 12 sample points and iii) upper rice fields at 850-1100 m.a.s.l. with a total of 12 sample points. This group of rice fields has two different straw management including a) burned straw was found at 600-850 m.a.s.l. (n=28) and b) buried straw was found at 850-1100 m.a.s.l. (n=12)

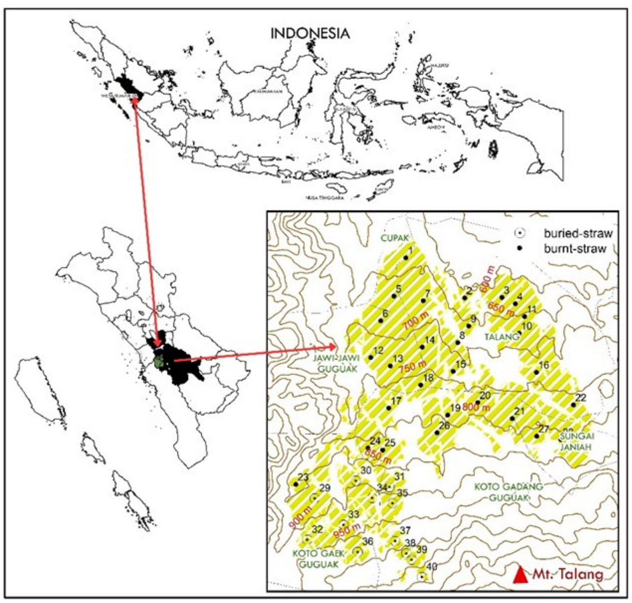

Figure 1. Map showing study site in Gunung Talang subdistrict, Solok Regency, West Sumatera

Laboratory analysis

Available Si was analyzed following of the modified method of Kitta & Mizouchi (1997). Soil samples < 2 mm were weighed as much as 2 g then mixed with 20 mL of 0.1 M acetate buffer pH 4 (1:10) in a 50 mL volumetric flask then covered and heated in a water bath at 40 °C for 5 hours.The measuring flask is stirred 10 times when initially placed in the water bath and at 0.5 ; 1 ; 2 ; 3 ; 4 and 5 hours after starting to heat. Then the solution was filtered using filter paper (Whatman 42) and the clear extract collected was measured using AAS (Shimadzu AA-6800).

Data analysis

All laboratory data were entered into the Microsoft Excel program and saved in CSV format. Subsequently, we conducted an ANOVA to assess the effect of elevation on available Si. A t-test was performed to compare the groups based on straw management. Additionally, a general linear model was employed to determine the relationship between pH and available Si. All statistical analyses were conducted using JMP 14 software. Map presentation was carried out using ArcGIS 10.4 software. In this phase, data processing utilized geostatistical methods, specifically Ordinary Kriging, which extrapolates values from sampled data to predict the distribution of nutrient content at unsampled locations. The resulting map depicts the Si status available at the research site.

RESULTS AND DISCUSSION

Availability of Silicon in rice fields in Gunung Talang District

The analysis of available Si content in the paddy soil of Gunung Talang District, conducted at 40 sample points, revealed a range of 10.48-293.66 mg/kg, with an average content of 133.34 mg/kg. This average value falls below the critical limit for soil available Si determined by Sumida (1992), which is <300 mg/kg. Among the samples, 18 locations exhibited available Si content >133.34 mg/kg, while the remaining 22 locations showed available Si content <133.34 mg/kg. Comparatively, the available Si content at this research site is lower than that observed in paddy fields in Subang Regency, West Java, which averages around 378 mg/kg, with an average available Si content of 172 mg/kg (Qurrohman *et al*., 2023).

The deficiency in available Si in paddy fields can be attributed to the absence of additional fertilizers containing Si or the failure to return plant residues that contain Si. This leads to inadequate Si replenishment, as Si is absorbed by plants during the growth phase. Numerous studies have demonstrated an increase in available Si in paddy fields with the application of Si sources. For instance, Liu *et al*. (2014) observed an increase in available Si from 40.4 - 94.0 mg/kg to 50.3 – 105.7 mg/kg at four out of six research locations following the application of corn straw biochar at a dose of 40 tons per hectare. Additionally, Song *et al*. (2013) found variations in available Si in paddy fields with the application of pig manure containing Si for 5 and 10 years compared to fields without such application, with Si content ranging from 133 mg/kg (without manure application) to 162 mg/kg (manure application for 5 years) and 267 mg/kg (manure application for 10 years).

The distribution of Si-available in the paddy fields of Gunung Talang District ranges from 50 – 100 mg/kg, covering an area of 265.88 hectares, predominantly in the upper paddy fields. Si availability in the range of 100 - 150 mg/kg spans an area of 639.05 hectares, occurring at several points within each rice field position. Meanwhile, Si-available in the range of 150 – 200 mg/kg covers an area of 620.34 hectares, distributed across several lower rice fields and the middle section (Figure 2).

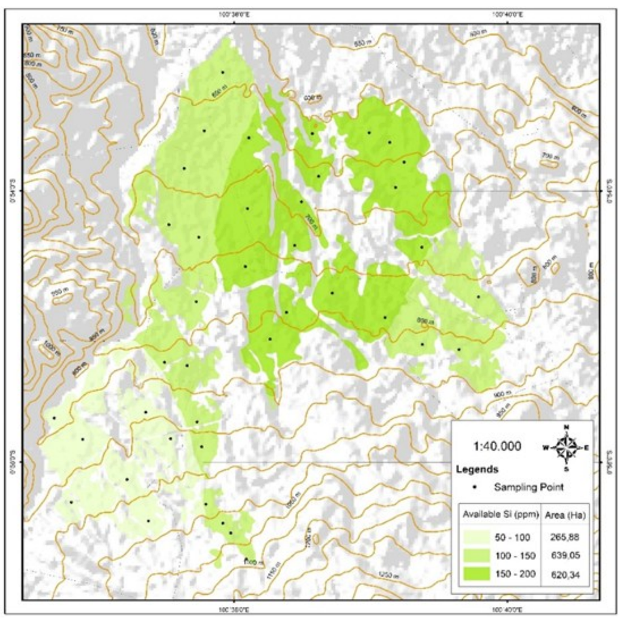

Figure 2. Available Si content of paddy fields soil in Gunung Talang District

Availability of Silicon in paddy fields based on elevation

The available Si content was categorized based on variations in the elevation of rice field locations, comprising three groups: lower rice fields (elevation 600 – 750 m.a.s.l), middle rice fields (elevation 750 – 850 m.a.s.l), and upper rice fields (elevation 850 – 1100 m.a.s.l) (Figure 3). The average available Si content ranged from 86.53 mg/kg to 158.98 mg/kg of soil. Concerning altitude, the lowest available Si was recorded at the highest elevation (850 – 1100 m.a.s.l), with a value of 86.53 mg/kg of soil. The available Si content increased with a decrease in altitude, reaching 145.96 mg/kg of soil in the middle (750 – 850 m.a.s.l) and 158.98 mg/kg of soil in the lower part (600 – 750 m.a.s.l).

The range of available Si (minimum and maximum) in the lower rice fields is 80.02 mg/kg and 293.66 mg/kg, while in the middle rice fields, it is 71.9 mg/kg and 228.4 mg/kg, and in the upper rice fields, it ranges from 10.48 mg/kg to 170.6 mg/kg. Based on a t-test significance level of 0.05, the available Si content in the lower rice fields did not exhibit a significant difference from that in the middle rice fields but significantly differed from that in the upper rice fields. Meanwhile, the available Si content in the middle rice fields did not show a significant difference from that in the upper and lower rice fields.

Table 1. Si distribution in paddy field along the toposequence

Land Position	Available Si (mg/kg)		
Lowland (n=16)	158.98	±	60.35[a]
Middleland (n=12)	145.96	±	52.00[a]
Upland (n=12)	86.53	±	52.37[b]
All position (n=40)	133.34	±	62.7

Note : Numeral show means ± standard deviation. Different letters indicate significant differences at $P<0.05$ among the land positions. Lowland = paddy field at 600-750 m.a.s.l ; Middleland = paddy field at 750-850 m.a.s.l ; Upland = paddy field at 850-1100 m.a.s.l ; All position = paddy field at 600-1100 m.a.s.l; n = total samples

This area is higly influenced by volcanic ash resulting from volcanic eruptions, which serves as one of the primary sources of Si availability in the soil. There is evidence suggesting that soil derived from volcanic and basaltic ash exhibits a higher Si content compared to soil derived from granite, quartz porphyry, and peat (Yongchao *et al*., 2015). However, the lowest available Si content was observed in the upper rice fields, at 86.53 mg/kg. Research conducted by Park *et al*. (2019) similarly found a decrease in available Si content in Andisol on Jeju Island at higher elevations (>600 m.a.s.l). It is assumed that there is a potential for Si loss through irrigation water due to the high solubility of Si. According to Darmawan *et al*. (2006), the Si content in irrigation water on the island of Java, Indonesia, is 14.00 mg/L SiO_2, which is believed to play a crucial role in maintaining the available Si content in the soil.

The intensive cropping system in the research location is identified as one of the causes of low available Si because the high Si uptake during the cropping period is not adequately compensated by Si return from inorganic fertilizers or harvested straw. The distribution of Si-available in the lower rice fields of Gunung Talang District ranges from 100–150 mg/kg, covering an area of 40.38 hectares, and from 150-200 mg/kg, covering 655.18 hectares. In the middle rice field soil, the distribution of available Si is more diverse, consisting of four criteria: 50-100 mg/kg (48.25 hectares), 100-150 mg/kg (236.06 hectares), 150-200 mg/kg (182.84 hectares), and 200-250 mg/kg (54.92 hectares). Meanwhile, Si -available in the upper rice fields ranges from 50–100 mg/kg, covering an area of 272.21 hectares, and approximately 100-150 mg/kg, covering 30.40 hectares (Figure 3).

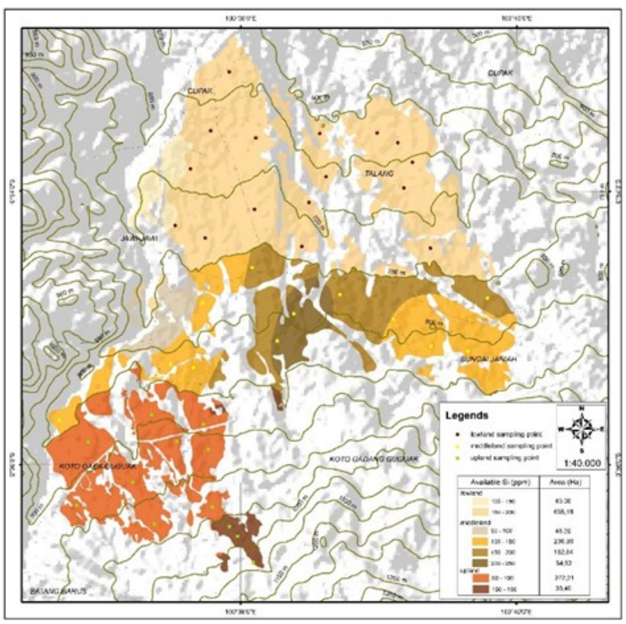

Figure 3. Available Si content of paddy field soil grouped based on differences in elevation

Availability of Silicon in paddy soil is grouped based on straw treatment

The Si availability status was categorized based on distinctions in post-harvest straw treatment, comprising two groups: burned straw (28 samples) and buried straw (12 samples) (Figure 4). From this classification, the mean available Si content was determined to be 153.40 mg/kg for burned straw and 86.53 mg/kg for buried straw.

The available Si range (minimum and maximum) within the burned straw treatment spanned from 71.9 to 293.66 mg/kg, while within the buried straw treatment, it ranged merely from 10.48 to 170.6 mg/kg. Utilizing a t-test at the 0.05 significance level, it was established that the available Si content in the burned straw treatment significantly differed from that in the buried straw treatment. This discrepancy indicates that Si availability derived from burned straw surpasses that from buried straw.

Variations in the management of rice harvest residues have been shown to impact the bioavailability of silicon (Si) in the soil (Klotzbücher *et al*., 2016). Rice straw, recognized as a silica source, can serve as a potential substitute for traditional fertilizers to meet silica requirements. According to Nandiyanto *et al*. (2016), heated rice straw contains approximately 85% SiO_2 of its total weight. Nevertheless, disparities in the handling of harvested straw can influence the soil's Si availability (Table 2). Notably, the Si content in areas where straw is burned significantly differs from those where it is buried.

Table 2. Effect of Straw Management on available Si

Straw Management	Available Si (mg/kg)		
Burned Straw (n=28)	153.4	±	28.8[a]
Buried Straw (n=12)	86.53	±	39.8[b]

Note : Numeral show means ± standard deviation.Different letters indicate significant differences at P<0.05 among the land positions. N = total samples

Research by Hughes *et al*. (2020) indicates that three different straw management practices (burning, incorporation, and conversion to manure) did not exert a significant effect on soil silica availability. However, the burning treatment exhibited the highest available Si content, aligning with the considerable potential for Si occlusion within pedogenic oxides/hydroxides.

The distribution of Si availability under burned straw management spans from 100 to 150 mg/kg, covering an area of 609.14 ha, and from 150 to 200 mg/kg, encompassing 613.50 ha (Figure 4). In contrast, Si availability in areas where straw is buried is notably lower, ranging from 50 to 100 mg/kg over 272.21 ha, and approximately 100 to 150 mg/kg over 30.40 ha.

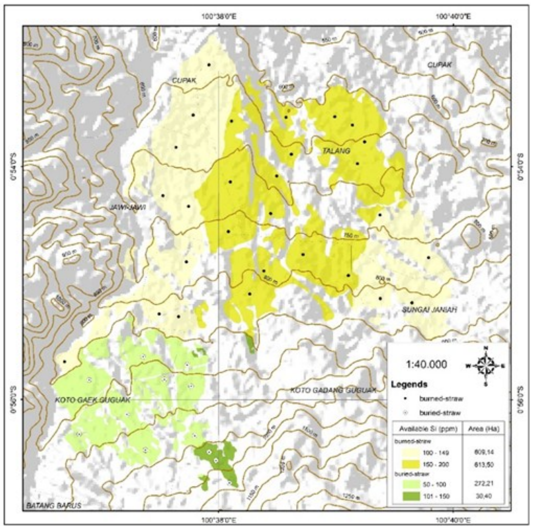

Figure 4. Available Si content of paddy field soil grouped based on differences in straw treatment

pH and Silicon content availability

The regression analysis between Available Si and Soil pH (H_2O) in paddy soil yielded a coefficient of determination (R^2) of 0.07 (Figure 5). Additionally, the regression output provided a correlation coefficient (r) of 0.27, indicating a weak association between Available Si and Soil pH (H_2O). Despite this weak relationship, it is noteworthy that the correlation value is positive. This suggests that an increase in available Si in the soil correlates with an increase in soil pH (H_2O).

As noted by Yanai *et al*. (2016), pH serves as a crucial factor determining Silicon availability in soil. They highlight a positive relationship between soil pH and monosilicate adsorption. Specifically, as soil pH increases (ranging from 4.00 to 9.00), there is an elevation in monosilicate adsorption, consequently enhancing Si availability in paddy soil.

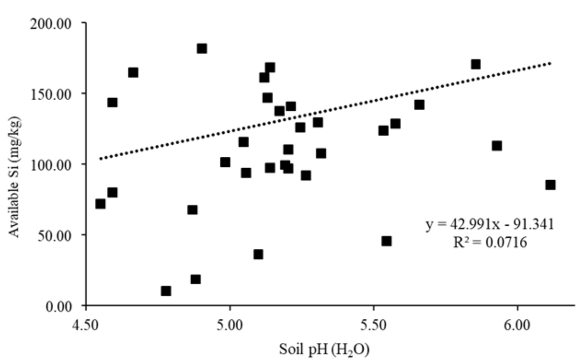

Figure 5. Relationship between available Si and soil pH (H_2O)

CONCLUSION

In Highland Paddy Fields, Silicon Availability ranges from 10.48 to 293.66 mg/kg, with an average available Si content of 133.34 mg/kg. The highest average content, reaching 158.98 mg/kg, is observed in the lower rice fields (600 - 750 m.a.s.l.), encompassing Nagari Talang, Cupak, and Jawi-jawi Guguak. Following this, the middle rice fields (750 - 850 m.a.s.l.) exhibit an average Si content of 145.96 mg/kg, covering Nagari Sungai Janiah and a portion of Nagari Koto Gadang Guguak. Conversely, the upper rice fields (850 - 1100 m.a.s.l.) present the lowest Si content at 86.53 mg/kg, including Nagari Koto Gaek Guguak and the majority of Nagari Koto Gadang Guguak. Silica availability is notably lower at sites where straw is buried (86.53 mg/kg) compared to those with burned straw (153.40 mg/kg). The study indicates a relatively low average availability of Si. Therefore, it strongly advocates for proper management of Si content in the soils, emphasizing the necessity for Si fertilizer supplementation.

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