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The Comparison of Erosion Rates in Grassland, Teak Forest, Crops Land, and Gliricidia Forest Plantation in Wanagama Edu Forest

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***Abstract*—Wanagama forest is an integral part of a nearby village. This forest is left unprotected, so local people can easily enter the forest area to take non-timber forest products, including cropland and grass. The increasing demand for grass for feeding the cattle in Wanagama resulted in a larger area of grassland. Therefore, it is highly important to review and measure the erosion rate of the grassland compared to other land uses. This research aims to measure the erosion rates of four land uses and determine the correlation between rainfall and erosion at those four land uses: grassland, teak forest, crops land, and Gliricidia forest plantation. In measuring the erosion rates, this research uses four plots of 22 x 4 meters established at those four land uses. Each plot has two drums at the outlet. We took the erosion samples at every single rainfall event. To investigate the rainfall, there were two ombrometers installed in the field. The results show that the grassland has the lowest erosion rate (0.45 tons/ha) compared to a teak forest (0.5 tons/ha), crops land (0.84 tons/ha), and Gliricidia plantation forest (1.66 tons/ha). The rainfall has a positive coefficient correlation to erosion; the lowest was in grassland (r = 0.723), followed by teak forest (r = 0.828), Gliricidia (r = 0.830), and Crops land (0.873). The higher the rainfall depth will result in the higher erosion rate at the four land uses.**

***Keywords*— Erosion; grassland; teak forest; crops land; Gliricidia; Wanagama.**

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I. INTRODUCTION

The establishment of Wanagama forest was in the year of 1964. Its area was a critical land then transformed back into a forested area. It has a hilly topography with high rainfall. The high rainfall intensity may cause soil erosion to rapidly transport the soil from its original place through an overland flow [1]. Soil erosion is defined as the wearing away of the topsoil layer. It occurs when the rainfall impact detaches and removes soil particles, either directly utilizing rain splash or indirectly by means of runoff [2]. Erosion is one of the most dangerous forms of degradation, causing the destruction of soils and the loss of their fertility [3]. The process of soil erosion causes an impact, both on the site of erosion (on-site effects) and outside the location of erosion (off-site effects). One of the effects of erosion is the loss of nutrients and soil structure damage on-site, while the impact at the off-site is the siltation of reservoirs, rivers, and other channels. Factors that affecting erosion is climate, topography, vegetation, and human activity [4].

Wanagama forest has several types of dominant vegetation such as teak, Gliricidia, crops land, and grassland. The difference in vegetation will affect the difference in erosion that occurs in each type of land. Teak plantations are thought to induce high erosion rates, which is usually attributed to as follows:

- Reduction in understory vegetation due to excessive light reduction and/or allopathy.
- Low organic matter accumulation due to low litter production.
- Increase in raindrop erosivity because the large leaves of the teak induce an increase in raindrop size [5], [6].

With the characteristics of the large teak leaves, the raindrops that fall and hit the surface of the leaves will accumulate. Then, the raindrops form larger rainwater with greater potential energy. Therefore, if large rainfall intensity occurs in teak forests, erosion will also increase.

Gliricidia sepium is one of the plants that provide environmental services, including soil erosion control and soil stabilization [7]. However, in Wanagama forest, they plant Gliricidia on hilly land so that erosion is possibly high. In addition, on Gliricidia forest, we found the rill erosion and the darker color of runoff, indicated that the land was eroded.

Wanagama forest is an integral part of a nearby village. This forest is left unprotected, so local people can easily enter the forest area to take non-timber forest products, including cropland and grass. Crops land is prone to erosion because of the tillage practiced in the farming area. It causes the progressive downslope movement of soil, resulting in soil loss from hilltops and soil accumulation at the base of hills [8]. Crops land is particularly susceptible to erosion because many farming practices remove the protective vegetation [9]. Tillage on cropland is carried out at the beginning of the rainy season by people who live around Wanagama I Forest, impacts on land openness, unable to withstand rainwater, and trigger erosion. In addition, continuous land use with no efforts to conserve land and water will cause a decrease in soil productivity [10], and the erosion process can be exacerbated [11], [12].

The increasing demand for grass for feeding the cattle in Wanagama resulted in a larger area of grassland. Grass harvesting leaves some part of grassland uncovered, which is more prone to eroded by rainfall, especially during the rainy season. The high erosion rate that occurred in a long continuous period will drive this land to become critical land [3]. Changes in land use caused by natural phenomena and human activities will result in land degradation. Soil degradation is a serious issue due to human actions [13]. Human action has influenced land use and land cover changes throughout activities such as farming, new settlement, land reclamation, industrialization, and urbanization [14].

Vegetation can reduce the speed and volume of surface flow, maintain the stability of the soil capacity to absorb water, and hold soil particles in place through the root system and litter produced [15]. Each type of vegetation can reduce the speed and volume of runoff. This is because each type of vegetation has different characteristics. In Wanagama, it is highly important to review and measure the erosion rate of the grassland compared to other land uses. This research aims to measure the erosion rates at the four land uses: grassland, teak forest, crops land, and Gliricidia plantation forest. This research also aims to analyze the relationship between rainfall and erosion rates at the four land uses.

II. MATERIALS AND METHOD

A. Research Site

This research was carried out in Wanagama Edu Forest (7°53'48.32"S 110°32'50.28"E) which is located in Gunungkidul District, 20 km Southeast from Yogyakarta City.

B. Research Methods

1) Erosion: This research consists of two kinds of data: erosion rates and rainfall depth. Both of these data are measured directly from the field. In measuring the erosion rates, 4 plots of 22 x 4 meters were established at four land uses: grassland, teak forest, crops land, and Gliricidia forest plantation. The plots figure of 22 x 4 meters is shown in Fig. 1. Each plot was completed with 2 drums at the outlet. We took the erosion sample from each drum of 500 ml, and then we dry them by using oven and weighted. Rainfall depth was measured using rainfall gauge namely ombrometer. There were 2 ombrometers installed in the field.

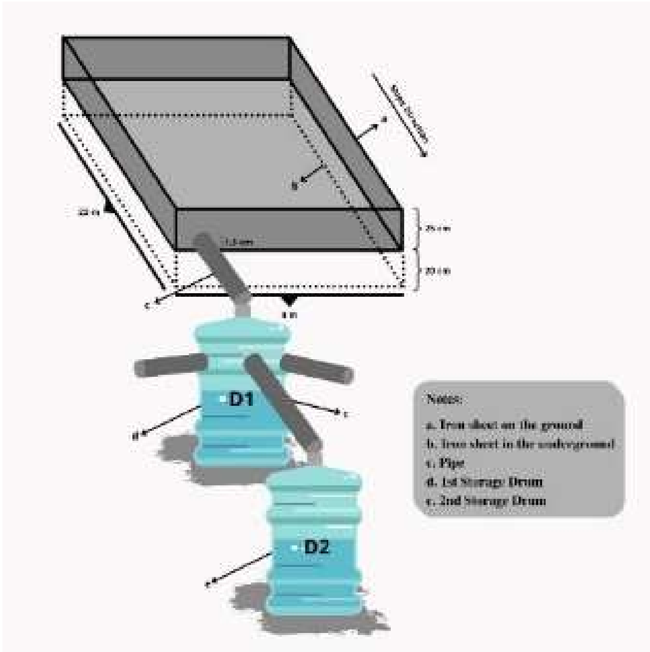

Fig. 1 Plots of 22 x 4 meters

The parameters observed in measuring erosion using small plots are:

- Amount of rainfall depth per rain event
- Sedimentation of soil in the drum collector
- Erosion that occurs on the land is calculated from the amount of sediment collected in the drum collector [16], and the calculation of erosion with a small plot method is as follows [17]:

1. Volume Drum (ml)

$$\frac{1}{4} \text{x } \pi \text{ x } d^2 \text{x TMA(cm)} \quad (1)$$

where,
d : diameter
TMA : water level (cm)

2. Runoff (RO)

$$\frac{\text{Volume drum}}{\text{Plot Area (cm}^2\text{)}} \text{ x 10mm} \quad (2)$$

3. Erosion Per Drum

$$W_D(g) = \frac{W_S}{V_S} \; x \; V_D \quad (3)$$

where,
WD (g) : erosion per drum
Ws (g) : suspension weight
Vs (ml) : volume of sample
Vd (ml) : volume of drum

4. Erosion (kg/ha)

$$\frac{W_{D_1} + (3 \text{ x } W_{D_2})}{\text{Plot Area (m}^2\text{)}} \text{ x } 10 \, {}^{\text{kg}}\!/_{\text{ha}} \quad (4)$$

where,
WD_1(g) : erosion on drum 1
WD_2(g) : erosion on drum 2
3 : number of holes on the drum

5. Erosion (ton/ha)

$$\frac{\text{Erosion (kg/ha)}}{1000} \quad (5)$$

2) *Vegetation:* Vegetation data is used to describe canopy cover (vertical projection) and canopy strata condition (horizontal projection) in the form of a profile diagram. The method used to determine canopy stratification is by establishing the measuring plot of 8 m x 60 m [18]. The following is a figure of the plot of vegetation cover:

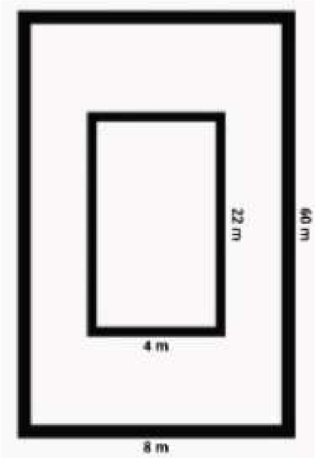

Fig. 2 Plots of Vegetation Cover

Plots are made around the small plots that have been installed. Data recorded were species, tree coordinates, diameter, branch-free stem height (tbbc), total height, canopy projection (north, east, south, west), and widest canopy position height. Vegetation data were analyzed using Sexi-Fs software to determine the appearance of vegetation from vertical and horizontal directions.

III. Results and Discussion

A. Erosion Rates

Soil erosion results from the action of erosion agents (water, winds, ice, and others) on the soil under actual natural conditions or conditions induced or modified by man. The erosion factor includes the natural and anthropogenic conditions that influence the erosion process's rise, development, and results. Factors such as rainfall intensity, rainfall volume, slopes, soil properties, land use, and land management determine soil erosion rates [19]. During the research period, 37 rainfall events resulted in erosion processes at 4 land-use types in Wanagama Edu Forest, as shown in Fig. 3.

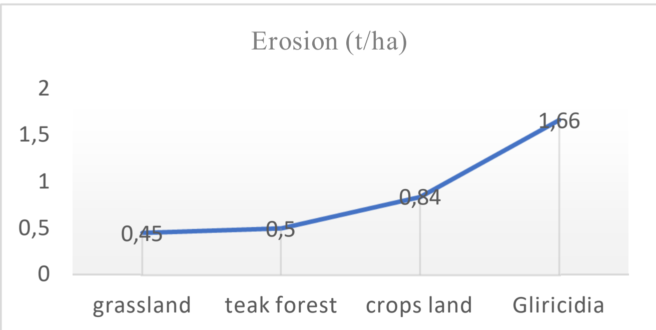

Fig. 3 Soil erosion rate at the four land uses

The average erosion rates are 0.45 tons/ha at grassland, followed by 0.5 tons/ha at teak forest, then 0.84 tons/ha at cropland, and the highest is 1.66 tons/ha at Gliricidia forest. The result of the erosion rate is served in Fig.3. The lowest erosion rate at the grassland was a result of the better coverage of the land. It helps the soil from the rainfall detachment. Besides, the coverage height is less than the teak, so the potential energy is also lower. Although this plot has no trees crown, the erosion rate is relatively low. This resulted from the two species of grass *Kolonjono* and *Gajah* grass, which functions to reduce the rainfall as well as runoff energy. *Gajah* grass (*Pennisetum purpureum)* is one of the plants that can control erosion [20].

The teak forest has an erosion rate that is almost the same as that of grassland because the teak forest has much hummus that contains high organic matter. This organic matter helps the soil for water infiltration, and on the other hand, the organic matter improves the soil aggregate stability. Humus also helps to protect the soil from the detachment of rainfall. The humus resulted from vegetation decomposition can protect the soil from the direct rainfall hit [3].

The cropland has a higher erosion rate than teak forest because the farmer disturbs the soil during the soil tillage. Tillage influences the higher erosion, and anthropogenic pressure had accelerated soil erosion rates [21], [22]. Another research stated that erosion occurs in cropland areas has higher than in forest areas [23], [24]. As a result, the soil structure was damaged, so; it will be easier to erode during the rainy season. The cropland does not have any trees canopy cover, so the rainfall mostly goes down and directly hits the soil. On the contrary, the croplands have a lower erosion rate than gliricidae because the cropland has more undercover crops and grass that help combat the runoff both quantity and its velocity, which reduces the kinetic energy erosion. The cropping system significantly influenced the soil organic matter [25].

The vegetation cover is supposed to have an inversed correlation with the rate of soil erosion. Conservation practices also have a crucial influence on soil erosion, especially in slopes areas [26]. The soil of this plot causes the highest erosion rate at Gliricidae forest is always wet, especially during the rainy season where the rain falls every day. Wet soils have slow soil infiltration capabilities that are causing runoff and increase the rate of erosion [27]. Moreover, the soil surface is covered by the dense crown so that the evaporation is less. The soil structure is a crumb, so the rainfall water has no chance to infiltrate into the soil but mostly becomes the runoff, which then its energy can transport the soil during the erosion process.

The canopy cover influences the forest microclimate, such as temperature, humidity, and solar radiation [28]. Besides, they have a lack of humus and forest floor, so that during the rainy season, part of the rainfall will be intercepted to the crown, and others will go down to hit the soil, then flows as the runoff. Moradi and Vacik [29] studied the relationship between vegetation types, soil, and topography in the Southern Forest of Iran. The result showed that this study could be used to restore vegetation or maintain species in ecologically sensitive areas.

To evaluate the erosion rates in these four areas, statistical analysis was applied. The statistical analysis showed that each pair of land use has a significant difference in their erosion rate. It means that the same rainfall resulted in different erosion at different land use.

TABLE I
STATISTICAL ANALYSIS RESULT

		t	Df	Sig. (2-tailed)
Pair 1				
Pair 2	E_TP - E_JT	5.959	29	.000
Pair 3	E_TP - E_RM	5.887	29	.000
Pair 4	E_GM - E_JT	8.156	29	.000
Pair 5	E_GM - E_RM	8.331	29	.000
Pair 6	E_JT - E_RM	2.112	29	.043

To count the total yearly erosion rate, the rainfall depth of the year 2017 was used, then calculated by the resulted regression equation. The yearly erosion rates were: 1.48 tons/ha/yr at the grassland; 1.62 tons/ha/yr at the teak forest; 2.71 tons/ha/yr at the cropland, and the highest was at the gliricidia amounted 5.29 tons/ha/yr. Based on the yearly erosion rate at the 4 land uses, the calculation continued to classify its erosion hazard index using the table. The index can be used as a standard in choosing the appropriate soil and water conservation practices. The cropland was classified as a moderate class, whereas teak forest is light class, gliricidia and grassland were classified as a heavy class. Ditch and slash treatment is an appropriate practice for sediment and soil loss control [30]. Furthermore, the criteria to locate soil and water conservation programs require maps of altitude, geology, vegetation cover, and land use [31].

B. The relationship of Rainfall and Erosion

Rainfall is the main factor influencing soil erosion because rainfall has detachment energy. Rainfall has the potential energy to hit the ground surface, damage the soil aggregate and then carry soil grains carried by surface runoff. Rainfall has several characteristics that affect erosion, including rainfall depth and rain intensity. The size of the rain will affect the amount of erosion that occurs in the annual period. The high intensity of the rain will make the soil more saturated faster so that it will produce surface flow which then, with the presence of the surface flow, transports the suspension from eroded soil. The relationship between rainfall and erosion can be analyzed using statistical analysis with Sigmaplot software. The Sigmaplot software was used, and the result is served in Table II as follows [32]:

TABLE II
THE RELATIONSHIP OF INTERVAL COEFFICIENT AND ITS LEVEL

Interval Coefficient	Level
0.800-1.000	Very strong
0.600-0.799	Strong
0.400-0.599	Moderately strong
0.200-0.399	Low
0.000-0.199	Very low

The result of relationship between rainfall and erosion is served in Table III as follows:

TABLE III
THE RELATIONSHIP OF RAINFALL AND EROSION

Type of Land	r
Cropland	0,873
Gliricidia forest	0,830
Teak forest	0,828
Grassland	0,723

Based on these results, it can be seen that rainfall has a positive coefficient correlation to erosion. The higher the rainfall depth will result in the higher erosion rate at the four land uses. The lowest was in grassland (r = 0.723), followed by teak forest (r= 0.828) and Gliricidia (r = 0.830). The higher correlation was in cropland (r = 0,873). The correlation between rainfall and erosion is strong in grassland and very strong in the teak forest, Gliricidia forest, and crops land. According to Dariah *et al.* [33], rainfall affects soil erosion where high levels of erosion occur when rainfall is high [33].

The relationship between rainfall and erosion is in Fig. 4 as follows:

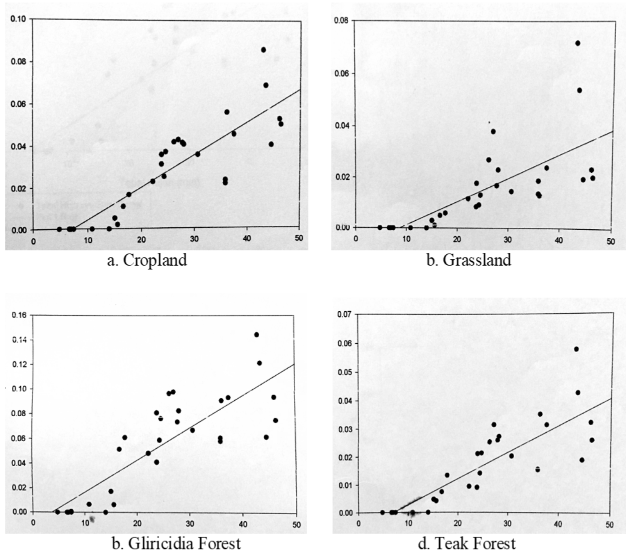

Fig. 4 The Graph of Relationship of Rainfall and Erosion

C. Runoff Values

Rainfall intensity plays a dual role, not only in detaching soil aggregates but also in enhancing sediment transport [34]. Runoff is water flowing above the ground that occurs when the precipitation intensity exceeds the soil's infiltration rate. Runoff can erode the top layer of soil, which can cause erosion. The results show the runoff from the largest to the smallest sequentially were grasslands (205.36 mm), cropland (196.12 mm), Gliricidia land (71.89 mm), and teak forest land (62.81 mm). Natural regeneration processes tend to improve soil ecosystem services, improve infiltration, and reduce surface runoff and soil erosion [35]. Then, surface runoff and erosion had led to the observed distribution of some soil properties along the steep slopes [36].

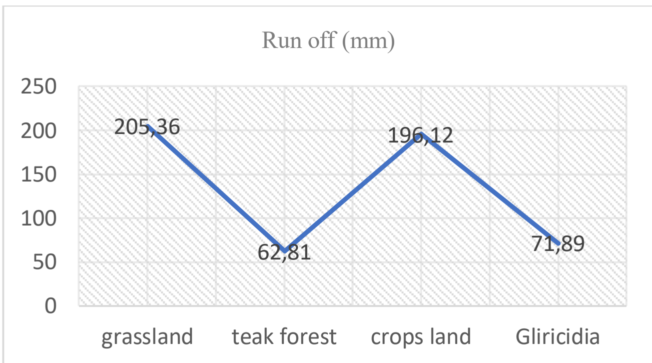

Fig. 5 Graph of Runoff Values

The difference in runoff values is a result of the different land cover conditions in each land use. Vegetation is the main factor that causes differences in runoff values. Each type of vegetation has distinctive characteristics in resisting runoff. Based on the results, the grassland has the greatest runoff value. This is because, in the grassland, no canopy can intercept falling rain that causes runoff. Like the grass land, the crops land lacks canopy cover so that the runoff of the crops land is also high. In addition, teak forestland has the lowest runoff. The teak forest has a canopy cover those functions to intercept rainwater. As well as on Gliricidia, the forest has canopy cover that can increase rainwater interception.

The teak forest has a canopy density of 73.37%, while Gliricidia is 86.03%. We calculate the forest canopy by using a profile diagram tools ArcMap 10.2.2 software. The profile diagram of teak and Gliricidia forest is served in Fig. 6 and Fig. 7 as follows:

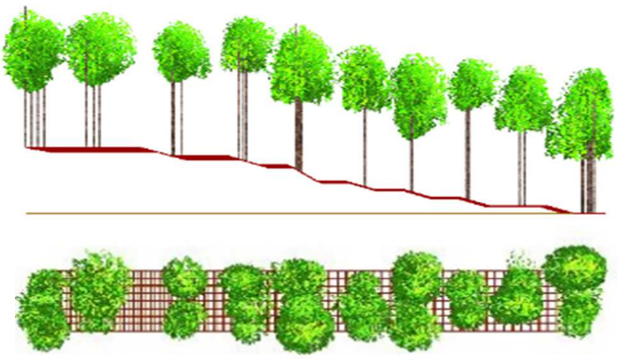

Fig. 6 The Profile Diagram of Teak Forest

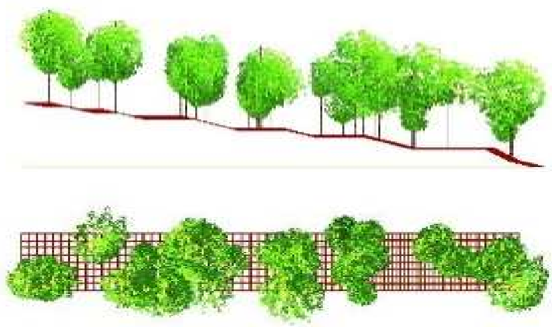

Fig. 7 The Profile Diagram of Gliricidia Forest

D. *Runoff Coefficients*

The runoff coefficient is a ratio of the runoff to the rainfall depth. This coefficient also shows the amount of rainwater that becomes runoff. The runoff coefficient value is between 0-1. A zero value indicates that all rainwater distributes into interception water, especially infiltration, while value 1 indicates that all falling rainwater is runoff. The number of runoff coefficients in the field is usually greater than zero and smaller than one [12].

The runoff coefficient has a notation C. The value of C is large if the value of C is equal to one. This condition is not profitable because the amount of water that will become groundwater will decrease. Another disadvantage is that the greater the amount of rainwater that becomes the surface flow, the greater the threat of flooding and erosion. In this research, the results of runoff coefficients are as follows: grasslands (0.27), cropland (0.26), Gliricidia (0.10), and teak forest (0.08). To obtain the runoff coefficient value, we divide the runoff with the rainfall depths obtained during the study. The result in the graph is shown in Figure 8.

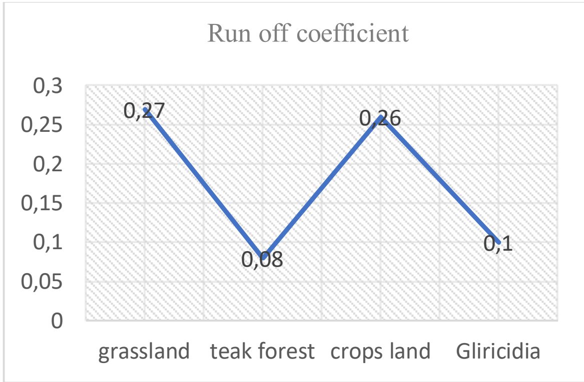

Fig. 8 Graph of Runoff Coefficients Values

IV. Conclusions

This research indicates that the erosion rate was 0.45 ton/ha at the grassland and the highest erosion rate was 1.66 ton/ha at the Gliricidia forest. At the grassland, there are two species of grass: Kolonjono and Gajah grass, which have the potency to reduce the rainfall and run off energy. The soil of this plot causes the highest erosion rate at gliricidia forest is always wet, especially during the rainy season where the rain falls every day. Factors that affecting erosion is vegetation, canopy cover, and runoff. The rainfall depth has a positive coefficient correlation to erosion. The lowest was in grassland ($r = 0.723$), followed by teak forest ($r = 0.828$), Gliricidia ($r = 0.830$) and Croplands (0.873). The higher the rainfall depth will result in the higher erosion rate at the four land uses. Correlation in the grassland is strong, and the teak forest, gliricidia forest, and cropland are extraordinarily strong. The higher the rainfall depth will result in a higher erosion rate.

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