ASSESSING SOIL EROSION OF TERRACE PADDY FIELD

EVALUATION DE L'EROSION DU SOL DANS LES RIZIERES EN TERRASSE

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ABSTRACT

The study aims to assess rice cropping and fallow on soil erosion rate of terraced paddy field. The economic value reduction due to the increase of soil erosion by keeping the land fallow is also evaluated using the replacement cost method. A 0.75ha terrace rice field was used to investigate the soil erosion under regular cultivation of rice in 2005, and plowing with green manure fertilizing in 2007. The result of the study shows that terrace paddy field under fallow with cropping green manure increases embankment collapse and soil erosion rate. The suspended solid of run-off sample reaches to 3400mg/L during heavy rainfall, which is much higher than the rate of 500mg/L during ponding period. The estimated annual erosion amount is 4.15ton/ha/yr in green manure period, much higher than the rice ponding period (0.77ton/ha/yr). Soil erosion rates calculate by the USLE using the best available data are considerably higher compared to the field measured values. It reveals that the soil conservation function of rice-terrace under cultivated and ponded conditions outperforms other land usage types. Moreover, terrace rice runoff significantly increases under the fallow with cropping green manure plant. The economic value reduction of fallow with cropping green manure plant quantified by the replacement cost method indicates that the cost of soil erosion from terrace field may increase ranging 12.1×10^6 ~ 13.5×10^6 NT$/year from 1999 to 2007 in Taiwan.

Key Wordsterms: *terrace rice field; soil erosion; rainfall-runoff; economic value.*

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RESUME

L'étude vise à évaluer l'effet de la culture de riz et de la jachère sur le taux d'érosion du sol de la rizière en terrasse. La réduction de la valeur économique en raison de l'augmentation de l'érosion du sol en tenant la terre en jachère est aussi évaluée utilisant la méthode de coût de remplacement. Un champ de riz en terrasse d'une superficie de 0,75ha a été utilisé pour examiner l'effet de l'érosion du sol sur la culture régulière du riz en 2005, et sa cultivation utilisant l'engrais vert en 2007. Le résultat de l'étude montre que la rizière en terrasse en jachère cultivée avec l'engrais vert augmente le taux de l'érosion du sol et de la possibilité l'effondrement d'endiguement.

Le taux d'érosion annuelle évaluée à 4,15ton/ha/an dans la période d'engrais vert est plus élevé que dans la période de flaquage de riz (0,77ton/ha/an). Les taux d'érosion du sol calculés par USLE utilisant les meilleures données disponibles sont plus hauts par rapport à ceux calculés utilisant les valeurs mesurées sur le champ. Il indique que le fonctionnement de la conservation de l'eau de rizière en terrasse dans le cas de cultivation et de flaquage donne meilleur résultat que dans le cas d'autres types d'utilisation de terre. La réduction de la valeur économique de jachère cultivée avec l'engrais vert quantifiée par la méthode de coût de remplacement indique que le coût de l'érosion du sol de rizière en terrasse varie de 12,1 × 106 ~ 13,5 × 106 NT$/an durant la période de 1999 à 2007 à Taïwan.

Mots clés: *Rizière en terrasse; érosion du sol; précipitation-écoulement; valeur économique.*

1. INTRODUCTION

Rapid economic development has caused a steep decline of agricultural labor in Taiwan. A large percentage of terraced paddy field has either been abandoned or converted to other useS. However, terraced paddy fields, located in middle and upper river valleys, perform many ecological and environmental functions including storing floodwater, preventing soil erosion, purifying water quality, and recharging of groundwater. Thus, the preservation of terraced paddy is an important environmental issue (Liu et al., 2004).

As promoted by government policies, the fallow paddy fields had mostly been converted to cropping green manure as well as growing upland fruit trees, vegetables and horticulture plants. Since only 50% survival rate of the green manure cropping can meet the government subsidy standard, farmers make little effort to maintain the green manure survival rate, and the bank of fallow fields for protection of sloping lands. The terrace fields therefore significantly reduce the soil and water conservation functionalities (Matsuno et al., 2006).

Soil erosion in the mountainous area is a well-recognized problem. Main drivers for soil erosion are topography, soil texture, rainfall patterns, land cover and land use. Numerous models have been developed and used to quantity and predict soil erosion. The Universal Soil Loss Equation USLE (Wischemeier and Smith, 1978) is a frequently used model to determine erosion-risk areas and help in decision making processes for long-term average erosion development in agricultural lowlands. The amount of potential soil erosion is calculated as

$$A = RKLSCP \quad (1)$$

where A is the average annual soil loss (ton $ha^{-1}year^{-1}$) due to erosion, R is the erosivity factor (Mj mm $ha^{-1}hr^{-1}year^{-1}$), *K* is the soil-erodibility factor (ton ha hr $ha^{-1}Mj^{-1}mm^{-1}$) and gives the soil's tendency to erode. *LS* is the topography factor combines slope length and slope steepness, which is the ratio compared the soil loss with that from a field of specified length of 22.6 meters with a 9% slope. *C* is a crop management factor, a ratio which compares the soil loss with that from a field under a standard treatment of cultivated bare fallow, and *P* is the conservation practice factor, a ratio which compares the soil loss with that from a field with no conservation practice. Using the USLE for estimation of soil loss, Misubishi Research Institute (MRI, 1991) indicated that the annual soil erosion rate increased 2.56 ton/ha for an abandoned rice paddy field with the gradient more than 1/20. Kim et al., (2006) also indicated that abandonment of paddy field will yield large amounts of soil erosion, of about 25 ton/ha on average. In Taiwan Lin and Lin (2004) used the USLE to evaluate the soil erosion rates of rice planting paddy and abandoned paddy fields assuming no plant cover on topsoil. The erosion rates increased from 4.8 ton/ha to 192.5 ton/ha for lowland rice planting and abandoned paddy fields in the plain area whereas the erosion rates increased from 8.3 ton/ha to 2049.8 ton/ha for terraced rice planting and abandoned paddy lands in mountainous area. Although the same USLE was applied for the estimation, significantly different results were drawn in monsoon Asia. The use of in-situ field measurement may resolve the large discrepancy.

The aim of this study is to determine the rice cropping and fallow with green manure planting on soil erosion rate of terrace paddy field. Since no erosion-prediction model for steep terrace rice field is available, we test the USLE as it is one of the mostly used erosion models worldwide. Moreover, the economic value reduction due to the increased soil erosion by fallow with green manure planting is evaluated using the replacement cost method. The results provide governmental agencies an evaluation basis to promulgate policies concerning the conservation of terrace rice field.

2. MATERIAL AND METHODS

1. Study Site

The 0.75ha experimental terraced rice field with uniform steep slope (about 25°) is located on Hsin-Chu county, north Taiwan (Figure 1). Terrace height is about 1.0m to 2.5m with gravel-packed slope surface allowing free drainage of water. The irrigation water is introduced from the near-by torrent intake, with pipelines, to the upper field block, and distributed via overflow to the entire blocks. The impact on soil erosion was investigated under regular cultivation of rice and fallow with green manure planting in 2005 and 2007, respectively. Figure 2 showed the environment of the terraced field under rice planting and under fallow with green manure planting in 2005 and 2007, respectively.

Fig. 1. Location of experimental site.

(a) Rice planting terrace paddy in 2005

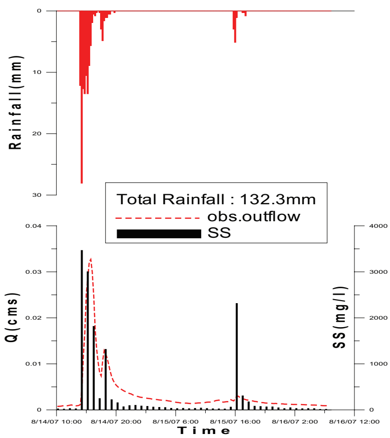
(b) Fallow with green manure planting in 2007

Fig. 2. Environmental conditions of Experiment Field

2. Soil erosion and runoff measurements

The legume green manure - Vicia dasycarpa – a creeping herbaceous plant, which is suitable to grow in sloping area of northern Taiwan, was extensively cultivated in the two crop seasons in 2007. After 3 month growing, the first crop of green manure was plowed and blended with soil in the end of June for the subsequent degradation process. The second-crop of manure was sown in September and plowed and blended with soil in end of November for natural degradation.

Field measurements included the hourly rainfall, the total suspended solid (SS) in the runoff and the volumetric discharge flux. An automatic rainfall recorder was set up in the downstream of the terraced field where water samples were collected at one hour interval during the rainfall events. The SS was analyzed following the standard method (ASTM, 1997). The volumetric discharge flux was measured using the triangular weir set up at the discharge point at the downstream of the terraced field (Figure 3). Total soil erosion due the corresponding rainfall event in the experimental terraced field was obtained by summing the product of SS and the volumetric discharge flux. The annual soil erosion rate was evaluated by the summation of the total soil erosion of all the rainfall events measured during the entire year.



(a)

(b) (c)

Fig. 3. (a) Rainfall, outflow and hydrograph of suspended soils during an afternoon thundershower on Aug. 14, 2007 (b) Environmental scenery and (c) High suspended solid outflow (Maximum SS was 3400 mg/L when field was in bare soil condition observed erosion reached to 615.85 kg).

3. Evaluation of soil erosion prevention value

The study used the replacement cost method to quantify the economic value of soil erosion prevention by rice planting terrace paddy. The data of annual soil erosion rate from terraced paddy land with standing rice plants and with fallow coupled with green manure planting were obtained from this study. The difference of soil erosion rates of these two farming practices was assumed to be remediated by constructing the soil erosion prevention dam. The unit cost for construction of soil erosion prevention dam is NT$ 603/m^3, (Taiwan Construction Research Institute, 2002). The soil erosion prevention value of the rice planting terrace paddy in Taiwan can be calculated as follows

(i) Compile the annual rice planting and fallow acreage and multiply by the percentage of terrace paddy/total paddy to obtain the rice planting and fallow acreage of terrace paddy.

(ii) Increase soil erosion rate result from fallow with green manure planting = (unit soil erosion rate of fallow - unit soil erosion rate of rice planting) × acreage of fallow terrace paddy.

(iii) Convert the increase soil erosion weight mass to volumetric soil erosion by the soil density and multiply by the unit cost of NT$ 630/m^3 for construction of the soil erosion prevention dame to obtain the soil erosion prevention value of the rice planting terraced paddy.

3. RESULTS AND DISCUSSION

1. Environmental change

Environmental change of the terrace field between rice cultivation and fallow with green manure planting is significant. Paddy rice cultivation is under flooded condition which makes top soil less susceptible to the rainfall; however the fallow with green manure planting is under upland condition where drainage ditches are generally constructed within the field blocks to allow free drainage of flooded water. The elevation of the discharge outlet in each block, therefore, must be lowered to the same elevation of the field surface. Upland condition also may cause formation of wormholes and cavities resulting from habitation and propagation of rats, earthworms and other animals, which increase the infiltration rate of the soil and cause an impact to the surface runoff after a rainfall. Moreover, soil erosion increases upon plowing, at the initial growing period and during the decaying period of green manure when the field is nearly in bare-soil condition.

2. Soil erosion

Total of five and four measurements of soil erosion caused by major rainfall events were made in 2005 and 2007, respectively (Table 1). Soil eroded conditions were compared by individual rainfall events. As the terrace paddy converted to fallow with green manure planting in 2007, the plum rain in June, thundershower in August (Figure 3) and two typhoons Wipha and Krosa (Figure 4) in September and October showed high SS and significantly soil erosion amount increased as compared with the terrace rice planting condition in 2005 (Figure 5) where observed SS values all below 500 mg/l and erosion amount were small. Moreover, the SS and soil erosion of four typhoons events in 2005 were all less than 150 mg/l and 60 kg, respectively. The SS can easily reach to 3000 mg/l and the average annual soil erosion rate was 4.2 ton/ha in fallow with green manure planting which was one order of magnitude higher and 5 times higher, respectively, than that of terrace rice planting period in 2005. However, the annual soil erosion rates of fallow terrace paddy with green manure planting was close to the clean-tillage terrace tea farming (4.0 ton/ha) and was much lower than the clean-tillage litchi and betel nut farming where annual soil erosion rate exceeded 300 ton/ha (Table 2).

Table 1. Erosion and peak flow caused by rainfall runoff in major rainfall events in 2005 and 2007.

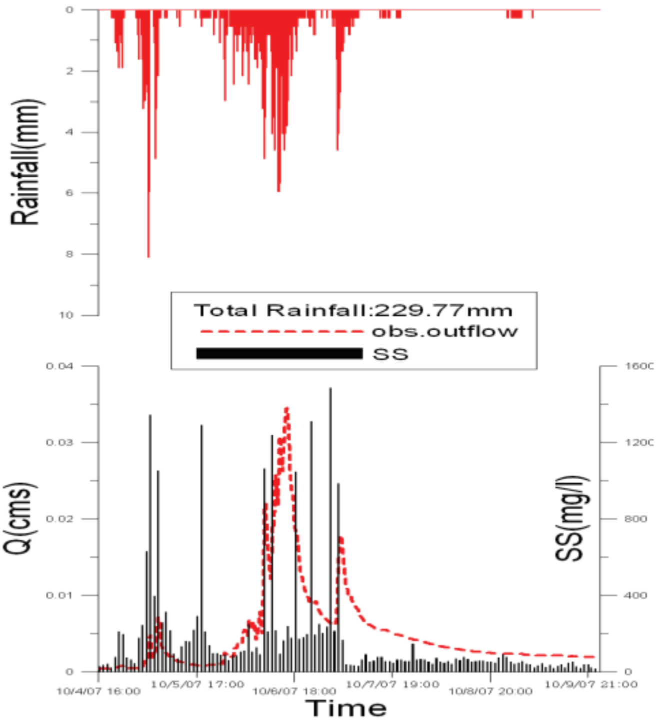
Rainfall event	Rainfall (mm)	Peak flow (cms)	Maximum SS (mg/l)	Erosion (kg)	Remarks
Typhoon Aere (2004 8/24~8/26)	473.0	0.0394	150.0	195.0 ~487.5	Soil-erosion is estimated with quality of water at SS 100~250mg/L. Collapses in two locations of ridge and overflow occurred
Plum rain (2005 5/9~5/16)	321.4	0.0182	422.9	315.1	First crop period of embankment collapsed by typhoon Aere was not repaired
Typhoon Haitang (2005 7/17~7/20)	123.6	0.0082	142.2	23.2	Second crop period of rice in land preparation-bund and embankment were well maintained
Typhoon Matsa (2005 8/4~8/6)	250.0	0.0143	138.4	55.8	Second crop period of bund and embankment were well maintained
Typhoon Talim (2005 8/31~9/1)	149.2	0.0131	65.0	12.1	Second crop period of bund and embankment were well maintained
Typhoon Longwang (2005 10/1~10/3)	36.2	0.0098	63.9	7.1	Second crop period of bund and embankment were well maintained
Plum rain (2007 6/3~6/10)	414.5	0.0190	3423.7	613.13 + 618.5	2 months after fallow green manure plants were cultivated (Erosion = erosion in the field + slope collapse in boundaries)
Thundershower (2007 8/14~8/15)	132.3	0.0331	3466.0	645.5	Field under land preparation period for green manure plants cultivation
Typhoon Wipha (2007 9/17~9/19)	189.5	0.0311	2566.7	285.3	Green manure plants had been cultivated for 3 weeks
Typhoon Krosa (2007 10/4~10/9)	229.8	0.0345	1486.9	617.2	Green manure plants had been cultivated for 5 weeks

The observed soil erosion results indicated that the rice planting terrace paddy highly preserved the soil conservation function. Lo and Hu (1997) estimated the annual soil erosion rates of the Sui-li Creek watershed in Central Taiwan using Agricultural Nonpoint source Pollution Method (AGNPS) which was 29.5 ton/ha. Ouyang (2003) used USLE to estimated the annual soil erosion rates of Shi-Men and Fai-Tsui watershed in Northern Taiwan which were 40 and 34 ton/ha respectively. Although these watershed areas were restrictedly protected for any land development, their annual soil erosion rates were still much higher than the terrace rice paddy.

Table 2. Comparison of soil erosion between terrace rice field with steep slope and other agricultural land uses.

unit: (ton/ha/year)

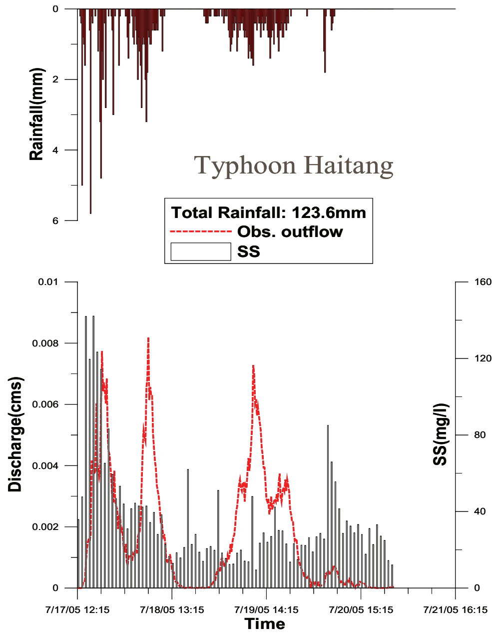
Different Agricultural Land Uses	Annual Average Soil Erosion	Remark
Steep slope bare field	407.3	1990~1993 average value of observations (Huang et al.,1994)
Clean-tillage litchi farming	386.6	1990~1993 average value of observations (Huang et al.,1994)
Clean-tillage betel nut farming	354.6	1990~1993 average value of observations (Huang et al.,1994)
Clean-tillage terrace tea farming	4.03	1996~2000 average value of observations (Lin et al., 2001)
Pounding cultivation in terrace rice field with steep slope	0.77	Estimation from runoff of rainfall and observations of SS collected in-situ in 2005 (This study)
Fallow of terrace rice field with steep slope and green manure planting	4.15	Estimation from runoff of rainfall and observations of SS collected in-situ in 2007 (This study)



(a)

(b) (c)

Fig. 4. (a) Rainfall, outflow and hydrograph of suspended soils during typhoon Krosa in Oct. 2007 (b) Environmental scenery and (c) High suspended solid outflow (Maximum SS was 1400 mg/L during typhoon Krosa and erosion reached to 617.17 kg).



(a)

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Fig. 5. (a) Rainfall, outflow and hydrograph of suspended soils during Typhoon Haitang in year 2005 (b) Environmental scenery and (c) Low suspended solid outflow (Typhoon Haitang approached during the land preparation period of the second crop of rice. Maximum SS of outflow reached up to 140mg/L in the initial stage, in the rest of the stages were under 40 mg/L).

3. Rainfall runoff

Five and four measurements of runoff caused by major rainfall events were observed in 2005 and 2007, respectively (Table 1). The runoff of terrace fallow with green manure planting was generally much higher than that of the rice planting terrace. For example, the runoff of Typhoon Krosa in 2007 was 2.41 times higher than the Typhoon Matsa in 2005, but the amounts of rainfalls were similar (230 versus 250 mm). The large runoff was attributed to the lowering of the discharge outlet height of paddy bund which prevented green manure plant immersion from flooded water.

The flooded terrace paddy performs a strong function on the soil water conservation than other types of land use. The governmental agency should formulate effective measures to sustainably maintain rice planting in the terrace paddy.

4. Erosion assessment with USLE

The USLE was originally parameterized for soil erosion evaluation in the United States. Modified versions for other regions as well as for different temporal resolutions has been developed in the past (Knoz et al., 2009). For our study, factors were chosen depending on the best suitability for our experimental site. The factors were either determined from field data or taken from literature values. Thus, we took not only the factors proposed by Wischmeier and Smith (1978) for USLE but also tried to get the most appropriate factors for our land use site since no special model is designed for terrace rice paddy field.

Factor *R* was estimated based on the formula proposed by Wischmeier and Smith (1958). Total of 27 rainfall events were observed in 2005 using the criterion of signal event where the accumulated rainfall exceeds 12.7 mm. The *R* value was 125,564 (Mj mm $ha^{-1}hr^{-1}year^{-1}$).

K factor is generally determined based on known soil properties (Wischmeier and Smith, 1978) and convert to SI metric units (Foster et al., 1981). To accurately calculate the *K* factor, we conducted measurements of soil properties including soil organic matter, soil structure, and soil permeability, contents of silt, very fine sand and sand (Table 3). Notably three sets of soil permeabilities were measured by field double ring infiltrameter test. The measured basic infiltration rates ranged from 0.05 to 1.13 mm/hr which were all smaller than 1.25 mm/hr. The derived *K* factor value was 0.75 ((ton ha hr ha-1$Mj^{-1}mm^{-1}$). The L factor value was 1.67 by substituting the horizontal length of 61.5 m to the formula proposed by Wischmeier and Smith (1965). Because the average slope of the experimental site was 25°, the S factor was set to 2 as suggested by Fan and Lovell (1990) for slope > 5.14°, C and P factors were set to 0.1 and 0.01, respectively, according to Lin and Lin (2004). By substituting all these factors to USLE, the estimated soil erosion rate was 4.23 ton/ha/year for the rice planting terrace paddy in the experiment site which was higher than the in-situ measurement of 0.77 ton/ha/year.

Although the erosion that calculated with the USLE was in the same order of magnitude compared to field measurement, there was still 5.5 times higher than the field measured rate. Several factors might affect the estimation result from USLE. However, if we used the values of S factors recommend by Wischmeier and Smith (1978) and McCool et al. (1978) of 13.67 and 6.6, the estimated soil erosion rates would be 28.9 and 14.0 ton/ha/year, respectively, which were 37.6 and 18.1 times even higher than our field measurements. This means that we have tried to get the best available data for factors used by the USLE in the study. The flooded area of terrace paddy is much larger than the slope area and the flooded area enclosed by the paddy bund which may affect the values of *C* and *P* factors. More field data measurement adjustments will need to support these factors values.

Table 3. In-situ soil property parameters used for computing the soil-erodibility K factor.

Organic matter (%)	Soil structure	Soil permeability	Silt + very fine sand (0.002~0.1mm) (%)	Sand (0.1~0.2mm) (%)	K factor (ton·ha·hr/ ha·Mj·mm)
3.8	1	6	91.34	2.67	0.075

5. Economic value of soil erosion reduction by terrace rice planting paddy

To assess the economic value of soil erosion reduction by terrace rice planting paddy, we first determined the area of the paddy field where their altitude exceeded 100 m and defined as the terrace paddy. We then used the determined area of terrace paddy to assess its economic value by the replacement cost method. The results are listed in Table 4. From 1990, the area of fallow terrace paddy gradually increased resulting an increase of annual soil erosion rate and the costs construction of soil erosion prevention dame were increased accordingly. If the terrace rice paddy fields were properly cultivated the annual construction costs of soil erosion prevention dame ranged from NT$121 – 135×$10^6$ can be saved and the soil water conservation can also be maintained.

Table 4. Spatiotemporal changes of soil conservation value of terrace rice field in north, central, south and island wide Taiwan (in 104 NT$).

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007
North	3,345	3,406	3,492	3,731	3,938	4,017	3,783	3,865	3,776
Central	4,917	5,028	4,917	4,891	5,287	5,087	5,074	4,715	4,826
South	1,206	1,195	1,173	1,206	1,215	1,257	1,239	1,269	1,305
East	2,637	2,715	2,842	2,943	3,093	2,953	2,996	2,721	2,635
Island wide	12,105	2,344	12,424	12,771	13,533	13,272	13,092	12,570	12,542

4. CONCLUSIONS

We determined in-situ annual soil erosion rates of terrace paddy by rice planting and by fallow with green manure planting of 0.77 and 4.15 ton/ha/yr, respectively, which were approximately 20 times lower than previously reported in literature. We also used the USLE coupled with the best available data for each factor to evaluate the soil erosion rate. The estimated soil erosion rate calculate by the USLE was 4.23 ton/ha/yr which was 5 times higher than our field measured result. Using other literature suggested values of USLE factors may result even higher estimated soil erosion rates. The large differences in erosion values are most likely attributed that the USLE fail to consider the miltifunctions of terrace paddy which can store flooded water and prevent soil erosion. The peak flows of terrace paddy with rice planting caused by major rainfall events were generally 2 times lower than that of fallow terrace paddy. The economic value reduction of fallow with cropping green manure plant quantified by the replacement cost method indicated that the cost of soil erosion from terrace field may increase ranging from NT$12.1×10^6 to 13.5×10^6 /year from 1999 to 2007 in Taiwan.

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