EVALUATION OF SATELLITE IMAGERY DATA FOR CROP YIELD SIMULATION IN SARABURI PROVINCE, THAILAND

Kulapramote Prathumchai[1], Masahiko Nagai[2], Kullachart Prathumchai[3], Anisara Pensuk Tibkaew[4]
[1]Department of Geography, Faculty of Social Science, Kasetsart University, 50 Ngam Wong Wan Rd, Lat Yao Chatuchak Bangkok 10900, Thailand, kulapramote.p@gmail.com
[2]Center for Research and Application for Satellite Remote Sensing Professor, Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2-16-1, Tokiwadai, Ube, Yamaguchi, 755-8611, Japan, nagaim@yamaguchi-u.ac.jp
[3]College of Population Studies, Chulalongkorn University, Visit Prachuabmoh Building Bangkok, Thailand, 10330 kullachart.pr@student.chula.ac.th
[4]Department of Geography, Faculty of Social Science, Kasetsart University, 50 Ngam Wong Wan Rd, Lat Yao Chatuchak Bangkok 10900, Thailand, anisara.pensuk@gmail.com

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ABSTRACT: Climate change could be a severe cause of disaster as well as food shortage. As the climate, society, and the environment change, these could bring more difficulties for agricultural planning because of unexpected decreasing yields of food crops; this could create a poverty situation. Therefore, an appropriate crop yield estimation methodology should be developed to help individual farmers plant crops. It is not only for adequate and safe food crops but also sustainable agricultural planning. A crop yield model is a technology that could be the best tool for farmers and researchers to develop yield products and farm management. Many crop-model studies have applied low-resolution data over a large area, and therefore the yield calculation of a whole district or village has resulted in the exact figure, whereas in reality, many paddy areas have a fragmented pattern with small rice plots.This study emphasized transplanted rice in a tiny area in Saraburi province. Field survey experiments have been conducted at observing rice characteristics to calibrate the crop parameters for local rice varieties. The cultivar-specific and agricultural practices were measured and evaluated. Integration of moderate-resolution satellite image and the AquaCrop model was performed to extract the essential crop parameters of paddy for yield simulation using the model. The green canopy cover (CC) information derived from the satellite data has provided acceptable results through the rice yield simulation and observed yield validation.

1. INTRODUCTION

Similar to many countries people, rice has been a staple food of Thai people for a long time. Referring to the country's statistics report, rice and its productions have been in top exporters in the world. (ARDA, 2021). Nevertheless, paddy cultivation is an important activity in agriculture worldwide. It is the staple food for most of the global people, which is expected to be 10 billion in the next 30 years. Therefore, food will be more demanded up to 60%. Precise in most present evaluations of the spatial allocation of rice cultivation areas are requested for all sections, including policymakers, farmers, and consumers. The accurate, suitable access is also crucial for water resource management, market price control, and food crisis management (Nguyen, 2017).

It is advantageous to apply technology to improve the rice yield and develop the quality of rice to satisfy demand. Smart Farm is a concept for the ideal farmer, which has been targeted for achievement by the Ministry of Agriculture and Cooperatives. Huaykhamin is a sub-district in Nong Khae district in Saraburi province, Thailand. The Rice Seed Production community area was selected for the pilot project, and it was the earlier smart farm model implementation project for rice fields. A turnkey project was introduced, which offers several kinds of services such as soil and fertilizer analysis. Moreover, this community has a concept for "tailor-made fertilizer" to reduce the cost of rice planting and decrease the amount of chemical fertilizer as well as then to develop into organic farming. (Arksornniem, 2013).

Forecasting the crop yield estimation is vital for agricultural planning and decision-making policies. Farmers need to make decisions for their cultivation plans as they have to calculate the cost and potential profit before investing in seedlings, materials, fertilizer, etc., which in most cases involves predictions that cannot easily be reversed (Maki et al., 2017). Traditional crop monitoring and yield estimation in many countries are mainly based on ground surveys and reports. These methods are costly and time-consuming. Empirical models have been developed using weather data but are associated with a number of problems due to the spatial distribution of weather stations. However, most of the crop models are complex in terms of data demand and manipulation, resulting in information being available very late, usually after the harvesting period (Prathumchai, 2014; Sawasawa,2013).

The AquaCrop model for yield simulation is a multi-crop model that requires a relatively lower number of input parameters (Nontikansak, 2011). However, some crop parameters are difficult to gather without the use of scientific equipment in the field observation. Remote sensing data can extract some necessary information. Due to the ability to view the Earth's surface by using remote sensing platforms in a repetitive manner, several remote sensing methods have been developed to map rice areas in different parts of the world (Mosleh and Hassan, 2015). Moreover, the AquaCrop model is a decision support tool that can be used for strategies planning for effective crop yield management, including predicting crop productivity, water requirements, and water-use efficiency under water-limiting conditions (Prathumchai et al., 2018; Jin et al., 2014).

However, AquaCrop should be tested in different locations before its widespread use in crop production prediction (Sam-Amoah et al., 2013). This study integrated the moderate-resolution satellite image (Landsat 8) with the AquaCrop model to simulate the yield of transplanted rice on small farms in a Rice Production Community as a pilot case study area to support agricultural planning policies in Thailand.

2. OBJECTIVE

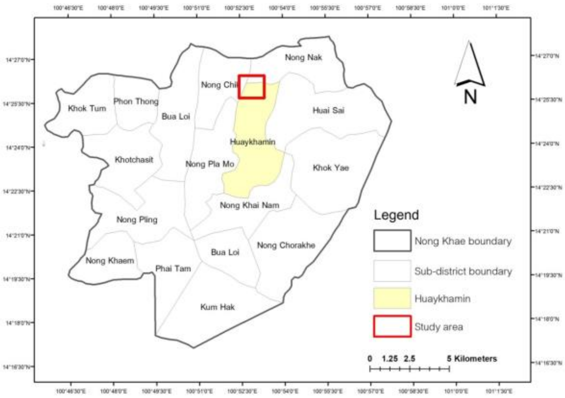
To evaluate the integration of satellite data and a crop model in a transplanted rice plot in Nong Khae district, Saraburi province.

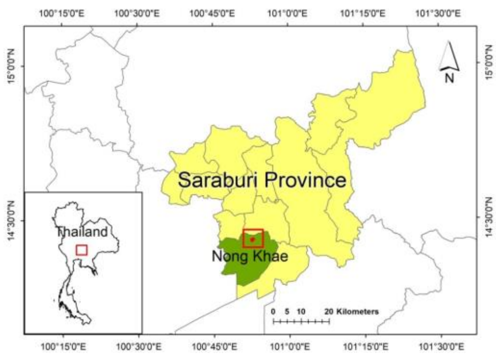
3. STUDY AREA

Saraburi is a designated province in central Thailand. Saraburi locates on the East side of the Cho Phraya river valley. The height of the s area is approximately 2 meters above mean sea level. There is a middle slope that resembles an alternating plain hill in the northern and eastern parts of the province. Pasak River flows through the northern part into the alternating plain hill, the Central part, and the Eastern parts of the plain. The total length is 105 kilometers. Consequently, the terrain is an obvious difference. It can be divided into two main features included an area in a mountain and plateau. Also, Saraburi is placed on the east side of the Chao Phraya river valley (Nontikansak, 2011).

Huaykhamin is a sub-district of Nong Khae district in Saraburi province, central Thailand. The geographic location is 14.42°-14.44 °N and 100.87°-100.89 °E (Figure1). Huaykhamin sub-district consists of 14 villages and has approximately 15.12 km^2 of agricultural land. Rice is the main crop, and most farmers cultivate it twice per year. The first rice planting (rain-fed paddy) occurs during the rainy season, from June to November. The second planting is in the dry season (irrigated paddy), from February to April. The topographical characteristics of the study area are flat land with small hills. Irrigation canals are available, and the Huaykhamin River runs through the area (Huaykhamin Community Rice Seed Center, 2012).

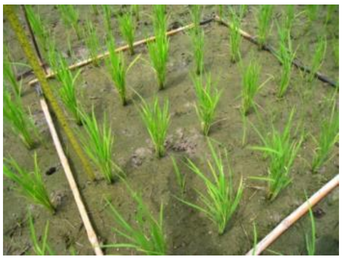
This area is one of several pilot projects begun in community-based rice farms in recent years. This community has 86 households with plantations of approximately 480 ha in total. This study focused on farmers using transplantation because this method produces the finest seed stock and because the transplanted rice area has occupied more than 40% of paddy area in 2009-2015 of Thailand. Thus, the sample rice plots which had transplanted methods and the same farmer were selected for the experiment (Prathumchai et al.,2018; OAE., 2016; Huaykhamin Community Rice Seed Center,2012).





The study rice-plot
Satellite image from Google Earth

Vegetation Stage



Rice age = 42 days

Reproductive Stage

Rice age = 98 days

Ripening Stage

Rice age = 125 days

Figure 1: Location of the study area and field observation in Huaykhamin sub-district of Nong Khae district in Saraburi province, central Thailand

4. MATERIALS AND METHODOLOGY

This study focused on a tiny rice plot for evaluation of the canopy data extracted from Landsat 8. The field observation data were conducted at the study area from July 13th, 2013, to October 27th, 2013. The farmer transplanted the rice by using the planting machine.

In order to run the AquaCrop model, five daily weather input variables (Table 1) and leaf growth are required. Compared with other models, AquaCrop is relatively simple to operate by those with little or no, research experience. It produces a high level of accuracy and requires only a limited set of input parameters, most of which are relatively easy to acquire (Prathumchai et al.,2018; Jin et al., 2016).

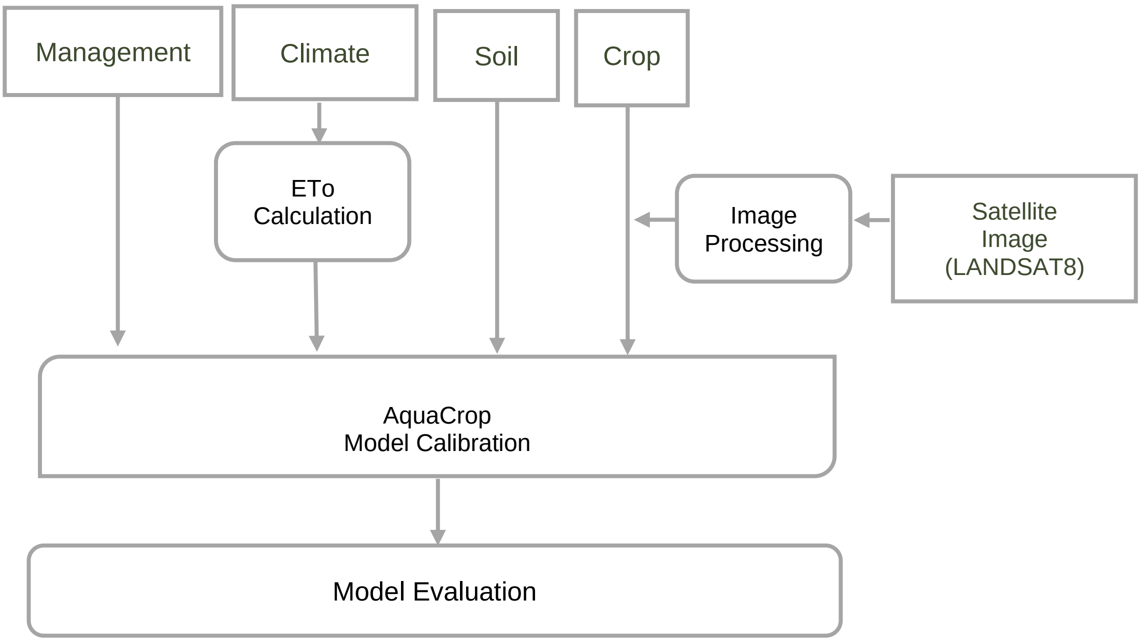


Figure 2: Flowchart showing the main concept of methodology

The general information of the field observation was 0.40 ha. Farmer used machine method for transplanting with rice verity's name RD49. The date of transplant and harvest was 9th July and 17th October in 2013. For more detail of data input. There are four main types of data required for the analysis: climate data, soil characteristics, crop characteristics, and field and irrigation management.

4.1 Management

Management included the agriculture practice and irrigation, as the observation period was conducted in the rainy season; therefore, irrigated status was expected to no-stress of water usage. The same as fertilizer management was defined to no-strass condition and no mulches covering on surface according to farmer's manners. Measurement of the bund height was made for all four sides of both rice plots. The average height of the bunds in the plot of the study was 0.49.

4.2 Climate data

The daily reference evapotranspiration (ETo) was computed using the full set of data based on the FAO Penman-Monteith method, as described in Allen et al. (1998), with the help of ETo calculator software (FAO, 2009). Daily climate data were obtained from a weather station established by NECTEC, and they contain temperature, rain, and CO2 data. The data were collected during the rainy season from June to December 2013. The average of weather data; rainfall was 1281.6 mm., the temperature was 27.3 C°, relative humidity 79.45 %, wind speed (2 m. above the surface) was 0.73 m/sec., and actual duration of sunshine a day was 6.64 hrs./day. As a result, the maximum ETo was 5.1, the minimum was 2.3, and the mean was 3.96 mm. per day. Subsequently, the default CO2, which the AquaCrop model arranged, was applied.

Table1: Summary of daily meteorology data from Huaykhamin weather station (Prathumchai, 2018)

Symbol	Climate parameters	Minimum	Maximum
Tmax	Maximum air temperature (C°)	25.9	36.8
Tmean	Mean air temperature (C°)	21.4	30.7
Tmin	Minimum air temperature (C°)	15.6	28.4
RHmax	Maximum relative humidity (%)	72.6	98.2
RHmean	Mean relative humidity (%)	58.2	97.1
RHmin	Minimum relative humidity (%)	39.2	95.3
u(x)	Wind speed (x m above soil surface) (m/sec)	0.05	4.18
n	Actual duration of sunshine in a day (hour/day)	0	9.83
ETo	Reference crop evapotranspiration (mm/day)	2.3	5.1

4.3 Soil data

The study area is approximately 250 meters from the soil measurement point. The measurement location was Lat.14.44, and Long.100.89 as observed by the Land Development Department (LDD, 2003). The soil series name of the study plots is "Manorom". The soil Manorom series is a member of the fine, mixed, semiactive, isoohyperthermic Aeric (Plinthic) Endoaqualfs. They are deep, very strongly acid soils. They are characterized by a brown loam, silty clay loam, or clay loam A horizon overlying a brown grading to grayish brown or light brownish gray argillic B horizon. These soils are mottles throughout with yellowish-brown and strong brown coating along root channels in the A horizon and prominent red and yellowish red mottle in the B horizon. These soils have plinthnite in the B horizon, with few to common spherical hard iron/manganese nodules occur in the deeper subsoil or throughout the profile. (LDD.,2021; Prathumchai,2018; Udomsri et al., 2004). Table2 shows five layers with different properties such as silty clay and clay, thickness, and other characteristics where PWP is Permanent Wilting Point, FC is Field Capacity, TAW is total available soil water in the root zone(mm.), Ksat is Saturated hydraulic conductivity (Ksat) and Tau is the dimension drainage characteristic (Prathumchai, 2018; Raes et al., 2012; Nontikansak, 2011), these values were calculated by the model.

Table2: Soil horizon profile characteristics

Horizon	Description	Thickness (m)	PWP (vol%)	FC (vol%)	SAT (vol%)	TAW (mm/m)	Ksat (mm/day)	tau
1	Silty clay	0.16	32.0	50.0	54.0	180	15.0	0.22
2	Silty clay	0.14	32.0	50.0	54.0	180	15.0	0.22
3	clay	0.30	39.0	54.0	55.0	150	2.0	0.11
4	clay	0.40	39.0	54.0	55.0	150	2.0	0.11
5	clay	0.65	39.0	54.0	55.0	150	2.0	0.11

4.4 Crop data

The local crop characteristics have been collected for the model calibration, consist of planting schedule, sowing density, effective rooting depth, flowering, and crop germination. The rice species developed by the Rice Department was grown in the rice plot, namely ‘RD49’. The rice plants were randomly measured about 9 points in the observed plot. The grain yield and rooting depth were determined within one square meter in the plot. Height of the plants at ground level, the time to emergence, maximum canopy cover, the first day of senescence, and maturity were recorded before they were cut for weighting. The parameters contributing to plant yield were plant height, plant density, and the number of rows and lines per square meter frame.

4.5 Remote sensing data and analysis

Landsat 8 Operational Land Imager (OLI) image was gathered for this analysis. The scene was acquired on path 129 and row 50. The image was acquired on 27th September 2013 that contains the test rice plot with the age of 95 days

(80 days from transplanting date). Thus, the rice was during the reproductive stage. A detailed technical specification of Landsat was red and near-infrared bands of vegetation analysis. Its technical specification is presented in Table 3 (USGS,2021).

Table 3. Technical specification of Landsat 8 OLI

Satellite	Band no.	Spectral range (μm)	Spatial resolution (m)	Repetition cycle (day)
LANDSAT 8 OLI	4	0.64~0.67 (Red)	30	16
	5	0.85~0.88 (NIR)	30	

- **Vegetation index calculation**

The normalized difference vegetation index (NDVI) is most commonly applied to optical images for crop information (equation 1) (Mosleh et al.,2015), and the outcome of the vegetation indices values can then be calculated for the leaf area index and canopy cover conversion. Where P_{NIR} was the reflectance of near-infrared and P_{RED} was red spectral bands. The NDVI calculation was estimated using the image.

$$NDVI = (P_{NIR} - P_{RED}) / (P_{NIR} + P_{RED}) \quad \text{(eq. 1)}$$

- **Relationship between NDVI and %CC**

The AquaCrop model uses a canopy cover (CC) value instead of leaf area index (LAI) (Zhang et al.,2013). In the previous experiment, using HJ1A/B and Plant Canopy Analyzer, the relationship between NDVI and %CC has been found, as illustrated in Figure 3. Because this study aims to extract the CC information from the satellite image thus, LAI measurement was not operated. In order to evaluate the satellite image data for the CC parameter, therefore, the relationship between NDVI and CC has applied the best fit with the polynomial method and another testing for the linear regression.

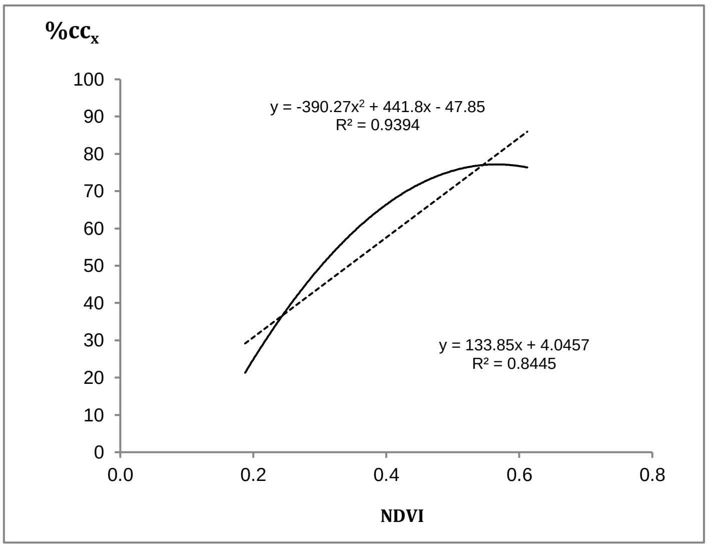


Figure 3: Relationship between NDVI and $\%CC_x$

4.6 AquaCrop Model Calibration and Evaluation

AquaCrop is a multi-crop water productivity model developed by the Land and Water Division of the Food and Agriculture Organization (FAO). It simulates the crop yields at different farm levels for water management strategies. The model requires a relatively low number of input data and parameters to simulate the yield response. The parameters are explicit and primarily intuitive; the model performs a balance between accuracy, simplicity, and robustness. This model is a valuable tool tested and applied worldwide to optimize irrigation management, simulate yield response, and improve crop production decision support. The crop yield is computed as a function of the final biomass and the harvest index, while the effects of water stress are isolated to the canopy growth, canopy senescence, transpiration, and harvest index. (Prathumchai et.al, 2018; Adhikari, 2014; Raes et.al, 2012; Hsiao et.al,2009)

- **Simulation and evaluation of rice yield using CC from Landsat**

As a result, the polynomial function can be used for canopy cover (CC) interpolation. The simulated maximum CC (CC_x) was used as a user-specific input for the rice plot. The other calibrated parameters in Table 4 and 5 were used as the input crop parameters for the test plots. The CC_x, which was generated using Landsat 8 image. Then, the yield was estimated using the AquaCrop model. In order to evaluate the simulated yield, a simple mathematical formula was used (equations 2). The results are presented in Table 6.

$$\Delta \text{Yield} = |\bar{O} - S| \qquad \text{(eq.2)}$$

ΔYield is the difference between the simulated yield and the average of the observed yield. $\bar{O}$ represents the average of the observed yield and S is the simulated yield.

- **Model parameters and calibration**

Calibration of this study was performed using conservative crop parameters available in the AquaCrop database. These conservative parameters are crop-specific, unchanged materially with time, management practice, geographic location, or climate. Crop parameters, including crop phenology, crop transpiration, biomass production, yield formation, and stress, were used to calibrate the model and simulate the crop yield. The conservative crop parameter values used in the calibration are listed in the FAO AquaCrop database (2010). Thus, the same conservative parameters values specified for rice in the FAO Reference (Raes et al., 2012) were input for this study. The other parameters are cultivar-specific or less conservative. The cultivar-specific parameters are affected by location, crop cultivar, condition of the soil profile, and management practices and must be specified by the user. Table 4 describes the cultivar-specific parameters observed during the field survey from July to October 2013.

Table 4: Cultivar specific parameters to input AquaCrop model

Description	**Value**	**Units/ Meaning**
Soil surface covered by an individual seedling at 90% emergence (cm^2/plant)	5	CC_o
Number of plants per hectare	2,000,000	Plant/ hectare
Time from transplanting to recover	1	days
Maximum canopy cover (CC_x)	CC_x	%
Time from transplanting to start of senescence	107	days
Time from transplanting to maturity, i.e. length of crop cycle	110	days
Time from sowing to flowering	65	days
Length of the flowering stage	15	days
Minimum effective rooting depth (Z_n)	0.30	m.
Maximum effective rooting depth (Z_x)	0.35	m.
Reference harvest index (HI_o)	36	%

5. RESULTS

5.1 NDVI to Maximum canopy cover (CC_x)

The polynomial and linear regression equations were applied to simulate the CC of the rice plot. The results of maximum canopy cover (CC_x) were calculated using NDVI calculation of the Satellite image and applied for the crop parameter inputs to the AquaCrop model. The calculated CC_x was selected at 63.13% and 54.42% (Table 5). The other crop parameters: crop phenology, biomass production, and yield information, were implemented using the calibrated crop parameters presented in Table 4.

Table 5: Summary of statistic of NDVI and Canopy Cover for the crop model

Statistic	NDVI	%CC_x *(Linear Regrssion)*	%CC_x *(Polynomial)*
Max.	0.38	54.41	63.13
Min.	0.34	49.84	57.62
Avg.	0.35	51.40	59.51

5.2 Simulated yield evaluation

The local crop characteristics' conservative and user-specific parameters have been assigned to the AquaCrop model for calibration. The details of the parameters are shown in Table 4. We have applied equation 2 for the model performance was evaluated. According to the farmer interview, the observed yield was compared to the simulated yield. The average observed yield of the test plot was 6.00 tons/ha. The simulated yield of the plot was approximately 5.37 tons/ha using CC_x = 63.13% and 4.89 tons/ha when applied CC_x = 54.41%. (Table 6).

Table 6. Evaluation of the performance of the model at simulating yield

%CC_X	Yield ($t\ ha^{-1}$)		ΔYield($t\ ha^{-1}$)
	Observed	Simulated	
63.13	6.00	5.37	0.63
54.41	6.00	4.89	1.11

6. DISCUSION AND CONCLUSION

This study used the AquaCrop model to simulate rice yield at a small plot and calibrate crop parameters using field observation data and the maximum canopy cover from Landsat 8 data. It is notable in Table 6 that 63.13 % CC_x calculated from the polynomial formula provides a more accurate yield than using the regression formula, and the simulated crop yield is 5.37 tons/ha. The difference of yield simulation (ΔYield) compared to the observed average yield was approximately 0.63 tons/ha. It seems that a higher % CC_x would simulate more yield. The performance of the simulated crop yield at the test farm was moderate. It would be the limitation of the number of images and the cloud cover. However, the result is acceptable. The suggestion for future research is to consider a more variety of satellite image data. Moreover, the increasing number of field experiments and areas would improve the crop yield simulation.

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