

Spatial yield assessment of sorghum (*Sorghum bicolor*) using DSSAT – CERES –Sorghum model in Solapur

ABSTRACT

Accurate estimation of crop yield is crucial for ensuring food security and effective policy making. This study focuses on the estimation of sorghum yield in the Solapur region of Maharashtra (India), employing the Decision Support System for Agrotechnology Transfer (DSSAT) model. Sorghum is the fifth largely produced staple crop of the world which also plays a vital role in the food security produced by India. Maharashtra has the highest area under the sorghum crop and Solapur has the highest area under the rabi sorghum with an area of 4.6 lakh ha standing 23% of the total area under rabi sorghum in the state, even though the productivity is less compared to other states these studies to some extent will help us to get a preharvest estimation of the crop. CCEs were conducted for rabi sorghum and the model was validated for the simulated yields; which have a range of grain yield from 611 to 1525 kg ha⁻¹ and showed error with less than 14% and it was evaluated with statistical models such R², Nash-Sutcliffe efficiency (NSE) and Normalized Root Mean Square Error (NRMSE) and results show as 84%, 0.84 and 0.07. This model can be used further used for the yield gap analysis, and climate change studies for the locations.

Key words: Sorghum, DSSAT, CERES, Spatial yield, Solapur

1. INTRODUCTION

Sorghum is one of India's most widely cultivated cereal crops, known for its ability to adapt to a variety of different agroclimatic conditions and for its versatility. Sorghum is mostly cultivated as a dryland cereal crop in India's Deccan Plateau, Central and Western India, with a few spots in Northern India. Since, its high mineral content, slow digestion, and high fibre content, it is nutritionally superior to other small grains like rice and wheat. Sorghum provides food and fodder security by reducing risk on a sustainable basis because it is typically grown in nutrient-poor soils in regularly drought-prone areas [1]. In addition to being economically valuable, it also has nutritive value, so it has become one of the most important ingredients in the agricultural landscape of our country. Sorghum plants are very hardy and can withstand high temperatures and drought. It is being successfully grown under atmospheric temperatures ranging between 15° C to 40° C and annual rainfall ranging from 400 to 1000 mm; It can be cultivated on a variety of soil types, but humus-rich clayey loam has been determined to be the best. However, healthy sorghum soil needs to have effective drainage because it can handle water logging better than maize. Its stover is important for animal feed and the grain for new value-added/processed food products such as popped sorghum, papad, porridge, rava and as an ingredient for umpteen Indian dishes like roti, dosa, khichdi, etc., a sign of its diverse utilization trends. Even though the crop is robust and versatile, it has faced drawbacks in terms of yield and reduction in acreage. Sorghum harvested area is in the decreasing trend from 13.041 m ha to 4.093 m ha observed from 1991 to 2020 with a trend value of $R^2=0.9788$; As the fifth largest producer of sorghum globally (Figure 1.), India plays a crucial role in meeting domestic consumption demands; from 1991 average yield data of sorghum is in non-significant increasing trend with highest productivity was observed in the year 2021, 2008 and 2020 [3].

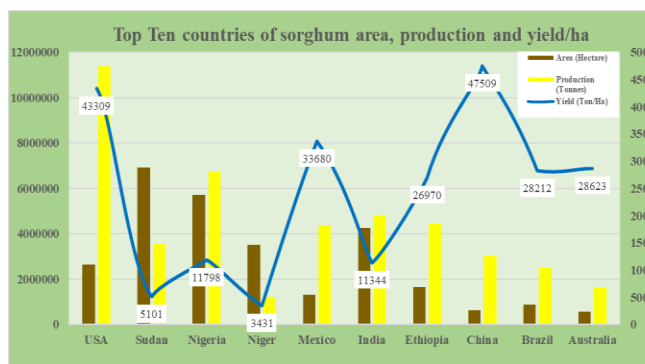


Figure 1. Top 10 countries of sorghum area, production and yield/ha (2019-20)

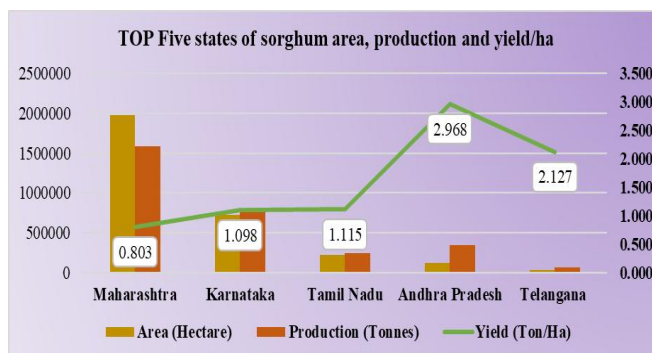


Figure 2. Top five states of sorghum area, production and yield/ha (2019-20)

In India, Maharashtra has the highest area and production followed by Karnataka, Tamil Nadu, Andhra Pradesh and Telangana (Figure 2.). In production wise Maharashtra and Karnataka stood top compared to Andhra Pradesh, Tamil Nadu and Telangana. But Andhra Pradesh and Telangana have the highest productivity this could be due to better irrigation facilities.

A timely, crop yield forecast has become essential to predict agricultural yield accurately well before harvest, especially in a nation like India where the weather is unpredictable. Accurate crop forecasting may become a strategy for guaranteeing food security in the current scenario of changing climate, growing susceptibility, and food insecurity. For several user groups, such as agricultural planners and policymakers, crop insurance firms, and the research community, early yield assessment at regional and national sizes is becoming more crucial [4]. In order to make informed decisions that affect markets, export-import choices, and agricultural revenue planning, accurate and timely monitoring of possible yields is essential [6]. To integrate agronomic sciences with information sciences, the main instruments required are crop simulation models. Through the mathematical and conceptual link that controls a plant's growth in the continuum of soil, water, plant, and atmosphere, it is now possible to replicate a living plant using these crop models. The interactions between the environment and the crops are largely explained by crop simulation models [11]. For small stakeholders of farmlands with standing crops becomes an intricate decision led by the government and policymakers for proper pricing of different insurance premiums. The Pradhan Mantri Fasal Bima Yojana (PMFBY) program of the Government of India aims to enhance sustainable production in the agriculture sector by giving financial assistance, stabilizing farmers' incomes, and encouraging farmers to use new techniques. The scheme provides insurance to farmers in the event of crop losses. The Mahalanobis National Agricultural Forecast Centre (MNCFC) in New Delhi, India, assesses agricultural acreage, yield, and crop conditions across the country to assist insurance firms in determining crop premiums. MNCFC has financed pilot studies in India to assess rapidly and accurately yield estimations utilizing techniques such as remote sensing and crop simulation modelling as part of this project [8].

2. METHODOLOGY

2.1 Study area

The district-level area estimates in Maharashtra, accounts for 81.5% of the production of Rabi sorghum in India. The Solapur district extends to an area of 14,89,500 ha and contributes 19% to states rabi sorghum production as of 2019-2020(Figure 3.) which is located at 17.10 to 18.32° North, 74.42 to 76.15° East(Figure4.) and this particular district accounts in the top two districts sown with the highest areas for rabi sorghum crop in its respective states. The experimental study was carried out in different locations in the Solapur district around 35 ground truth points (Figure 6.) along Crop Cutting Experiments (CCE) data were collected at random locations of experimental study and used for validation of the CERES model.

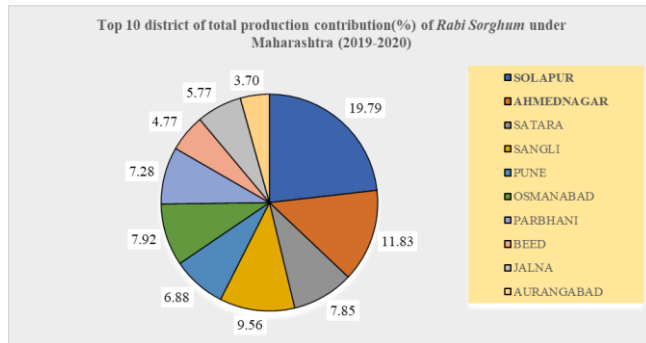


Figure 3 Maharashtra top ten districts with most rabi sorghum crop Area

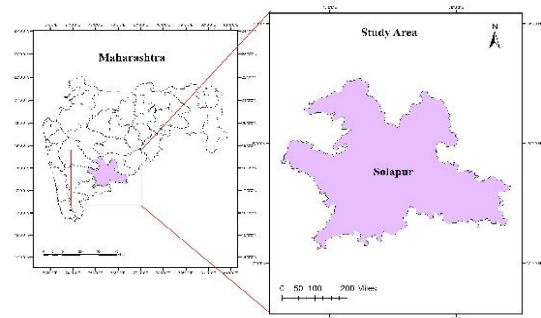


Figure 4.: Study area location Solapur (Maharashtra)

2.2 Minimum Datasets:

2.2.1. Input data:

Data was downloaded from NASA POWER (Prediction of Worldwide Energy Resource) for the duration of the Rabi season from 2nd fortnight of October, 2022 to 1st Fortnight of February, 2023. By weatherman a program in the DSSAT software is used to make the weather file and 35 files were made for the point-specific location and their graph maps are in (Figure 5.); which were considered as the monitoring sites in which the date of sowing was set from 5-28th of October as of data collected during ground truthing and the soil files were gathered from the International Research Institute for Climate Society, Michigan State, University Harvest Choice, International Food Policy Research Institute at 1:10,000 scale with a 5-min resolution. These files were the inputs to the model for the monitoring fields for the study area to be simulated. The crop management data of the file given was the rainfed crop.

2.2.2. Weather files of DSSAT:

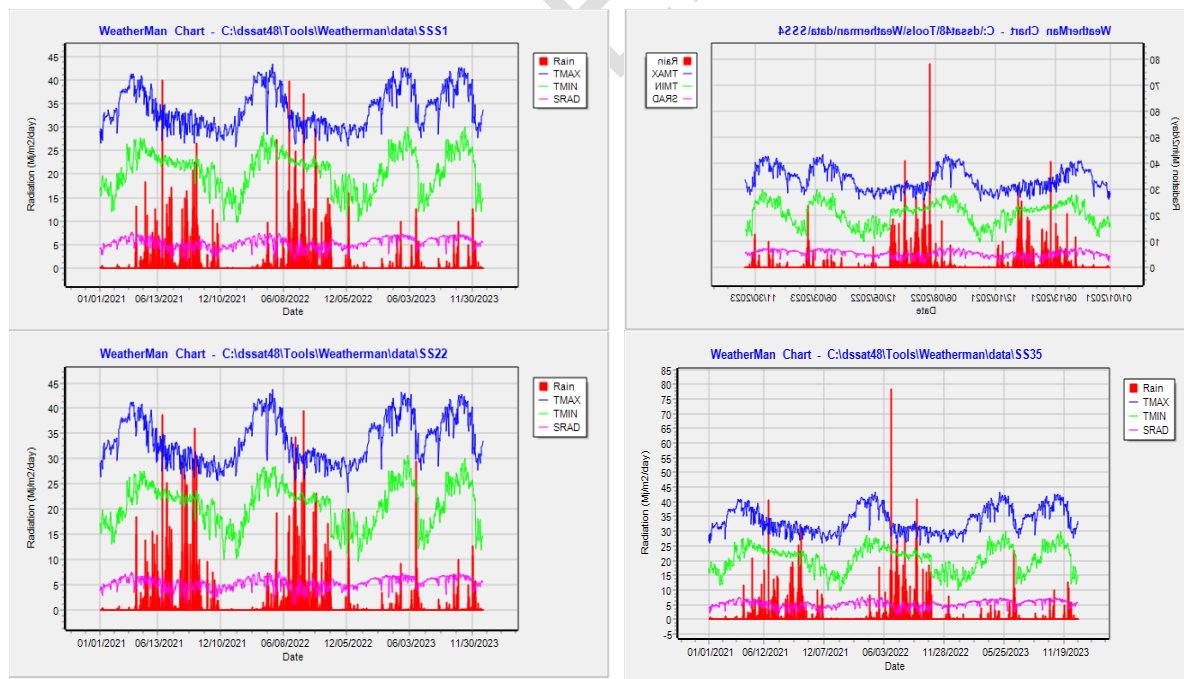


Figure 5.: Weather file for Solapur (Maharashtra)

2.3. Statistical Approach of Model Evaluation

The model's performances were evaluated using statistical indices including the coefficient of determination (R^2), Nash Sutcliffe model Efficiency coefficient, and % Error to evaluate the model's goodness of fit and performance. [15]

2.3.1 Pearson's correlation coefficient (r) and coefficient of determination (R^2)

$$R^2 = 1 - (RSS/TSS)$$

R^2 = Coefficient of determination

RSS = Sum of squares of residuals

TSS = Total sum of squares

2.3.2 Nash Sutcliffe model Efficiency coefficient:

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance [17]. Nash-Sutcliffe efficiency indicates how well the plot of observed versus simulated data fits the 1:1 line. $NSE = 1$, corresponds to a perfect match of the model to the observed data. $NSE = 0$, indicates that the model predictions are as accurate as the mean of the observed data, and $-\infty < NSE < 0$, indicates that the observed mean is a better predictor than the model.

where OBS_i is the observation value and SIM_i is the forecast value and \bar{OBS} is average of observation values.

$$NSE = \frac{\sum_{i=1}^n (OBS_i - SIM_i)^2}{\sum_{i=1}^n (OBS_i - \bar{OBS})^2}$$

2.3.3 NRMSE (Normalized Root Mean Square Error):

The Normalized Root Mean Square Error (NRMSE) the RMSE facilitates the comparison between models with different scales. the normalized RMSE (NRMSE) which relates the RMSE to the observed range of the variable. Thus, the NRMSE can be interpreted as a fraction of the overall range that is typically resolved by the model.

$$NRMSE = \frac{RMSE}{\bar{O}}$$

where \bar{O} is the average of observation value and you can find the formula of RMSE by click on it.

2.3.4 % Error (Deviation) is calculated:

The values of the % error for each point location is given in the table2.

$$\%Error = \frac{\text{simulated} - \text{observed}}{\text{observed}} * 100$$

2.4 CERES-sorghum genetic coefficients:

The calibration of the CERES – Sorghum module of the Decision Support system for Agrotechnology transfer (DSSAT), data on plant growth and development, soil characteristics, weather, and crop management were collected as required for determining the cultivar coefficients of as prescribed in the following the procedures described in International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). These coefficients allow the model to simulate the performance of diverse genotypes under different soil, weather and management conditions. To determine the genetic coefficients of Sorghum, the calibrated values are obtained by permutating and computing the values to determine the variation in the magnitude of output manually. Then, those values of the genetic coefficients that was found most realistically simulated the growth and yield of rabi sorghum were selected. The data set for genetic coefficients calculations include days to anthesis, days to first pod, days to physiological maturity, days to harvest maturity, seed yield, by-product leaf area and harvest index. The procedure for determining genetic coefficients involved in running the model using a range of values of each coefficient, until the desired level of agreement between simulated and observed values was reached.

3. Results and Discussion

3.1 Genetic Co-efficient of sorghum for CERES sorghum model:

The field experimental data collected during 2020-21 and 2021-22 during the Rabi season for three sorghum varieties namely Maldandi (M-35-1), Mauli and Yashoda and the genetic coefficients of varieties present in InfocropV2.01 model [11] were used. The details of the coefficients derived and converted into DSSAT genetic coefficients in which Maldandi (M35-1) was already existed then Mauli and Yashodha were derived from the permutation and computation [16]. In (Table No.1) calibrated CERES Sorghum module with data on plant growth and development, soil characteristics, weather, and crop management were collected as required for determining the cultivar coefficients were given in the table.

Table 1: Calibrated genotypic coefficients for rabi sorghum cultivar

| Coefficient code | Description | Genetic coefficient | | |
|------------------|---|---------------------|-------|----------|
| | | Maldandi (M35) | Mauli | Yashodha |
| P1 | Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above TBASE during which the plant is not responsive to changes in photoperiod) | 320 | 300.1 | 282.1 |
| P2 | Thermal time from the end of the juvenile stage to tassel initiation under short days (degree days above TBASE) | 102 | 102 | 102 |
| P2O | Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P2O, the rate of development is reduced | 14 | 12.46 | 12.46 |
| P2R | Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O | 45.6 | 111.1 | 123.1 |
| PANTH | Thermal time from the end of tassel initiation to anthesis (degree days above TBASE) | 617.5 | 617.5 | 617.5 |
| P3 | Thermal time from to end of flag leaf expansion to anthesis (degree days above TBASE) | 152.5 | 152.5 | 152.5 |
| P4 | Thermal time from anthesis to beginning grain filling (degree days above TBASE) | 81.5 | 81 | 81 |
| P5 | Thermal time from beginning of grain filling to physiological maturity (degree days above TBASE) | 590 | 450 | 525 |
| PHINT | Phylochron interval; the interval in thermal time between successive leaf tip appearances (degree days) | 49 | 54.02 | 54.02 |
| G1 | Scaler for relative leaf size | 15 | 7.2 | 7.2 |
| G2 | Scaler for partitioning of assimilates to the panicle (head). | 4.5 | 5.6 | 5.6 |

3.2 Yield Analysis

The observed yield and simulated yield are compared, and their Standard error is calculated. Among the 35 locations yield data were validated. For all the varieties in the given district were simulated well with the simulated yield with locations taken under the map in (Figure 6.) and (Table 2.) of yield.

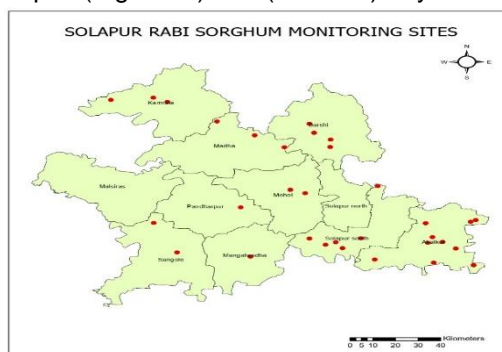


Fig 6. Solapur monitoring sites

Table. 2 Observed and simulated yield for Solapur Monitoring Sites

| Latitude | Longitude | Obs. Yield (Ha) | DSSAT Yield (Ha) | sim. | % error |
|-----------------------|------------------|------------------------|-------------------------|-------------|----------------|
| Variety- M35 | | | | | |
| 17.49481 | 75.82144 | 1020 | 923 | | -9.5 |
| 17.51930 | 75.92020 | 945 | 989 | | 4.7 |
| 18.14387 | 75.73508 | 1054 | 1023 | | -2.9 |
| 17.49609 | 76.24502 | 1085 | 1121 | | 3.3 |
| 17.70210 | 75.44345 | 1140 | 1112 | | -2.5 |
| 18.05813 | 75.61789 | 998 | 1040 | | 4.2 |
| 17.82788 | 75.98696 | 1525 | 1445 | | -5.2 |
| 17.45936 | 75.84884 | 1030 | 1115 | | 8.3 |
| 17.51730 | 75.71688 | 1160 | 1115 | | -3.9 |
| 17.60783 | 76.17765 | 1150 | 1101 | | -4.3 |
| 17.45923 | 76.29715 | 1178 | 1129 | | -4.2 |
| 17.80615 | 75.64110 | 1145 | 1082 | | -5.5 |
| 18.21058 | 75.35038 | 980 | 1010 | | 3.1 |
| 18.32605 | 75.15290 | 1057 | 1157 | | 9.5 |
| 17.40990 | 75.48366 | 940 | 1034 | | 10.0 |
| Latitude | Longitude | Obs. Yield (Ha) | DSSAT Yield (Ha) | sim. | % error |
| Variety- Mauli | | | | | |
| 17.52420 | 76.20540 | 1012 | 943 | | -6.8 |
| 18.35189 | 75.09761 | 910 | 894 | | -1.8 |
| 17.37428 | 76.20953 | 1021 | 947 | | -7.2 |
| 17.62613 | 76.37560 | 903 | 878 | | -2.8 |
| 17.61536 | 76.35649 | 920 | 878 | | -4.6 |
| 17.49202 | 76.18707 | 800 | 684 | | -14.5 |
| 18.33834 | 74.92818 | 900 | 976 | | 8.4 |
| 17.60783 | 76.17765 | 910 | 943 | | 3.6 |
| Latitude | Longitude | Obs. Yield (Ha) | DSSAT Yield (Ha) | sim. | % error |
| Yashodha | | | | | |
| 18.06008 | 75.79819 | 780 | 868 | | 11.3 |
| 18.10370 | 75.80110 | 775 | 854 | | 10.2 |
| 17.80615 | 75.64109 | 750 | 845 | | 12.7 |
| 17.43568 | 75.19119 | 939 | 1030 | | 9.7 |
| 18.19766 | 75.71659 | 936 | 858 | | -8.3 |
| 18.14387 | 75.73508 | 788 | 859 | | 9.0 |
| 17.45923 | 76.297146 | 700 | 633 | | -9.6 |
| 17.39322 | 75.97563 | 941 | 946 | | 0.5 |
| 17.78650 | 75.69935 | 932 | 845 | | -9.3 |
| 17.35854 | 76.36807 | 945 | 966 | | 2.2 |
| 17.60904 | 75.09834 | 700 | 787 | | 12.4 |
| 18.12800 | 75.49930 | 611 | 672 | | 10.0 |

3.3. Validation of model

The observed yield of sorghum was matched well after calibration which showed that model could simulate the yield with high accuracy, as it showed R², Nash-Sutcliffe efficiency (NSE) and Normalized Root Mean Square Error (NRMSE) is as 84%, 0.84 and 0.07 this indicates a good efficiency [6] also observed that the simulated biomass yield was slightly higher than that of the observed biomass yield in rice while using the DSSAT model. R² values show a good significant value for the graph of observed and simulated yield values. The R² values are good and significant, the 1:1 line graph was drawn showing observed yield in X-axis and simulated yield in Y-axis. The regression line of grain yield was near to the 1:1 line, indicating that the model was performing well under the test environment, thus model simulated the yield perfectly (Figure 7.)

R² value 84% for grain yield of Rabi sorghum was observed and similar coefficient of correlation value was observed after validation of CERES -CROPGRO module at Vidisha and Nagaur for chickpea. [13] A model showed “fair” to “good” in grain yield prediction by comparing the observed yields as of the [14] has observed similar evaluation results of the model in spring maize in northeast China showed almost similar evaluation figures in normalized root mean squared error (nRMSE), Nash-Sutcliffe efficiency (NSE).

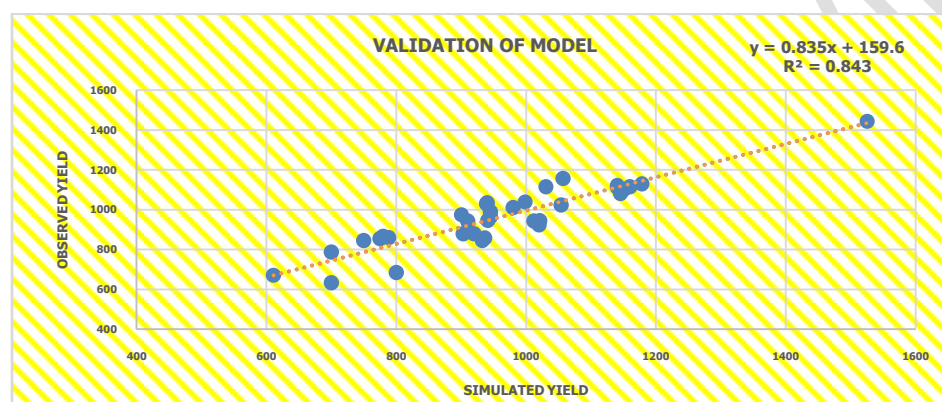


Figure 7. Simulated and observed yield for validation

4. CONCLUSION

The simulated yield of the DSSAT CERES Sorghum module revealed that simulated the yield were very closer to observed crop yield and it has proved to be a valuable tool for predicting sorghum yield. Therefore, the validated DSSAT can be further used for applications such as prediction of crop growth, phenology, potential and actual yield, climate change impacts, adaptation and vulnerability studies, yield gap analysis etc.,. The model can also be used to evaluate and improve the current practices of sorghum to increase the yield. CERES module can be used to simulate crop growth and its development as well as THE prediction of yield spatially for different conditions of soil, weather and management practices to enhance Sorghum production. It could be concluded that the model works well for in rainfed growing environments and further, it can be taken for application in natural resource management and climate change impact analysis studies.

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