



Evaluation of CROPGRO-Tomato Model under Different Dates of Planting and Cultivars under Semi-arid Environment

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Abstract

A field investigation was undertaken during *Kharif* (June–September) 2019 at Agriculture Research Institute, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad, Telangana State, India with an object to evaluate the CROPGRO-Tomato model under different dates of planting and cultivars. The experiment was carried out with dates of planting (02nd Jul, 12th Jul, 22nd Jul, 02nd Aug, 11th Aug, 23rd Aug, 03rd Sep and 13th Sep) as main plot treatments and cultivars US 440 and TO-3251 (Saaho) as sub-plot treatments. The CROPGRO-Tomato model performed well in the simulation of phenology, biomass, fruit yield and N uptake during calibration for US 440 and TO-3251. Calibration results revealed that the model perfectly predicted days to anthesis with no difference between simulated and observed data for both cultivars with RMSE of 0 days, the further model simulated the days to last picking, biomass at maturity, fruit yield and nitrogen uptake with RMSE of 0.9 and 0.7 day, 285 and 435 kg ha⁻¹, 545 kg ha⁻¹ and 389 kg ha⁻¹ (dry weight), 6 and 5 kg ha⁻¹ for US 440 and TO-3251 cultivars respectively. The calibrated model was used to further validate the experimental data and found that, simulation of days to anthesis and days to the last picking was excellent with NRMSE value of less than 10% for both cultivars, fair with dry matter production with NRMSE value of 25% for both cultivars and was poor with total fruit yield greater than 30% and N uptake for both cultivars under study was poor with NRMSE value more than 30%.

Keywords: Biomass, CROPGRO-tomato, cultivars, dates of planting, phenology, yield

1. Introduction

Tomato (*Solanum lycopersicum* L.) is the second largest cultivated vegetable crop and one of the most widely consumed vegetable in the World after potato. Tomato can play an important role in human diet and known as protective food because of its special nutritive value and also its wide spread production. It was an excellent source of vitamin A, C and K along with good sources of antioxidants and phyto-chemical compounds, including lycopene, β -carotene and flavonoids (Chandni et al., 2020).

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely

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grown vegetable crops in the World (Chattopadhyay and Paul, 2012). The global production of fresh and processing tomatoes increased by 300% during the last four decades (Costa and Heuvelink, 2007), reaching around 160 million tons in 2017 (Pathak and Stoddard, 2018). India is the third largest producer of tomato in the world after USA and China (Sharma et al., 2019). Tomato is one of the most important protective food crops of India having an area of 880 thousand hectares with an annual production to the tune of 18227 thousand metric tonnes, contributing to 9.4% of total vegetable area and 11.5% of total vegetable production. The productivity of tomato in India (19.6 mt ha⁻¹) is much less than the average productivity (28.2 mt ha⁻¹) of the world (Anonymous, 2009). In Telangana, it occupies an area of 41,480 hectares primarily under irrigated conditions with a productivity of 28.24 mt ha⁻¹ (Anonymous, 2018).

Traditional agronomic experiments are conducted at particular points in time and space, making results site and season specific, time consuming and expensive. In recent years, several process based dynamic crop simulation models has been developed that predict crop growth, development and yield using a systems approach, where that integrates the knowledge of underlying processes and interaction of different components of crop production. Simulation modeling can be a powerful tool to analyze the relationships among soil, plants, air, and other components in agricultural systems, particularly through studying the relationships between system components over time (Lenz-Wiedemann et al., 2010). In the last decades, several tomato models have been focused on different research topics e.g., TOMGRO, TOMSIM, TOMPOUSSE and CROPGRO-Tomato (Boote et al., 2012). Scholberg et al. (1997) adapted the CROPGRO-Peanut model for establishing CROPGRO-Tomato model to simulate growth, yield and yield components of the field grown tomatoes. Modeling the growth of field-grown tomatoes should assist growers and extension workers throughout the world to outline optimal crop management strategies for specific locations and production systems. These models were developed, not only to understand the processes and interactions involving system components and their effects upon overall production, but also for their usefulness as decision support tools for identifying best management options for attaining optimal production (Deligios et al., 2012). Among various crop growth models, CROPGRO-Tomato model was used to calibrate and validate the growth, development and fruit yield of tomato in different parts of India (Safia, 2015). For this region, DSSAT CERES-Maize model was used to calibrate and evaluate the popular maize hybrid (Rani et al., 2016) and further this validated model was used to identify the optimum sowing window and nitrogen levels under rainfed conditions in a semi-arid environment (Rani et al., 2014). However, So far no such model was used for the tomato to calibrate and validate the experimental data for this region with popular cultivars in order to make management decisions

to improve the productivity under open field conditions. Keeping the above points in view the present study was conducted to calibrate and evaluate the CROPGRO-Tomato model using experimental data.

2. Materials and Methods

The field experiment was conducted at Agricultural Research Institute, Rajendranagar, Hyderabad, Telangana State, India during 2019 *kharif* (June-September) having 17°19' N Latitude, 78°23' E Longitude and 542.3 m above mean sea level. The experiment was laid out in split plot design with eight dates of planting (02nd Jul, 12th Jul, 22nd Jul, 02nd Aug, 11th Aug, 23rd Aug, 03rd Sep and 13th Sep) as main treatments and two cultivars (US 440 and TO-3251) as sub treatments, replicated thrice. The soil of the experimental site was sandy loam in texture, neutral in reaction, low in available nitrogen, phosphorus and high in available potassium. The other package of practices were used as for the recommendations for raising the crop.

In the present experiment to assess the role of simulation models in agronomic research, the Decision Support System for Agro-technology Transfer (DSSAT) v4.7 CROPGRO-Tomato model was used. The model was calibrated using an iterative approach proposed by Hunt et al. (1993) and Godwin et al. (1989) to generate a suitable set of coefficients through trial and error adjustments to match the observed crop phenology and yield with those simulated by the model.

Statistically based criteria provide a more objective method to evaluate the performance of the model (Ducheyne, 2000). Simulation performance was evaluated by calculating test statistics like root mean square error (RMSE) (Wallach and Goffinet, 1989). Time course simulation of crop biomass and fruit yield was assessed by an index of agreement (d) (Willmott, 1982) that is an aggregate overall indicators. These measurements were calculated as follows.

$$RMSE = \left[\frac{\sum_{i=1}^n (p_i - O_i)^2}{n} \right]^{0.5}$$

$$d = 1 - \frac{\left[\frac{\sum_{i=1}^n (p_i - O_i)^2}{n} \right]}{\left[\frac{\sum_{i=1}^n (|p_i| + |O_i|)^2}{n} \right]}$$

Where P_i and O_i are the predicted and observed values for studied variables, respectively and n is the number of observations. Model performance improved as d value approaches to unity. A smaller RMSE indicated less deviation of the simulated from the observed values. Normalized RMSE (NRMSE) gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% (Loague and Green, 1991). The NRMSE

was calculated following equation.

$$\text{Normalized Root Mean Square Error} = \left[\frac{\text{RMSE}}{\bar{O}} \right] \times 100$$

The Coefficient of Residual Mass (CRM) was used to measure the tendency of the model to overestimate or underestimate the measured values. The CRM is defined by

$$\text{CRM} = \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n O_i}$$

Where, O_i and P_i are the observed and predicted values respectively for the i^{th} data point of n observations. A negative CRM indicates a tendency of the model towards overestimation (Xevi et al., 1996).

3. Results and Discussion

3.1. Calibration of genetic coefficients

For calibration of genetic coefficients of US 440 and TO-3251 was estimated by repeated iterations until a close match between simulated and observed phenology, growth and yield was obtained. The CROPGRO-Tomato model performed well in the simulation of growth, phenology, fruit yield and biomass during the calibration process across the first four planting dates D_1 (02 Jul), D_2 (12 Jul), D_3 (22 Jul) and D_4 (02 Aug) for US

440 and TO-3251. The genetic coefficients of selected cultivars were presented in Table 1. Calibration results revealed that (Table 2) model perfectly predicted days to anthesis with no difference between simulated and observed data for cultivars US 440 and TO-3251 with RMSE of 0 days between simulated and observed values across different planting dates. CROPGRO-Tomato model showed excellent simulated having less than one day difference with RMSE of 0.9 and 0.7 days for US 440 and TO-3251 respectively.

The simulation of crop biomass at maturity was also match well with RMSE of 285 and 435 kg ha⁻¹ for US 440 and TO-3251 respectively. There was a good agreement between observed and simulated fruit yield with RMSE of 545 kg ha⁻¹ and 389 kg ha⁻¹ (dry weight) for US 440 and TO-3251 respectively. In the case of nitrogen uptake simulation was well with RMSE values of 6 and 5 kg ha⁻¹ for US 440 and TO-3251 respectively. In all the cases the d-stat value was ≥ 0.70 .

3.2. Model validation

CROPGRO-Tomato model was validated with the data sets obtained from the remaining dates of planting D_5 (11 Aug), D_6 (23 Aug), D_7 (03 Sep) and D_8 (13 Sep) from the experiment conducted during the year 2019 with two cultivars (US 440 and TO-3251). The corresponding simulation results were

Table 1: Genetic coefficients of US 440 & TO-3251 used for CROPGRO-Tomato model

| Coefficients | Description of coefficients | US 440 | TO-3251 |
|--------------|--|--------|---------|
| CSDL | Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour) | 12.33 | 12.33 |
| PPSEN | Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour) | 0.00 | 0.00 |
| EM-FL | Time between plant emergence and flower appearance (R1) (photo thermal days) | 24.0 | 24.0 |
| FL-SH | Time between first flower and first pod (R3) (photo thermal days) | 4.9 | 4.0 |
| FL-SD | Time between first flower and first seed (R5) (photo thermal days) | 26.0 | 21.0 |
| SD-PM | Time between first seed (R5) and physiological maturity (R7) (photo thermal days) | 37.5 | 41.0 |
| FL-LF | Time between first flower (R1) and end of leaf expansion (photo thermal days) | 52.0 | 52.0 |
| LFMAX | Maximum leaf photosynthesis rate at 30 C, 350 vpm CO ₂ , and high light (mg CO ₂ m ⁻² -s) | 1.40 | 0.95 |
| SLAVR | Specific leaf area of cultivar under standard growth conditions (cm ² g ⁻¹) | 325.0 | 330.0 |
| SIZLF | Maximum size of full leaf (three leaflets) (cm ²) | 325.0 | 800.0 |
| XFRT | Maximum fraction of daily growth that is partitioned to seed + shell | 0.90 | 0.73 |
| WTPSD | Maximum weight per seed (g) | 0.0040 | 0.0030 |
| SFDUR | Seed filling duration for pod cohort at standard growth conditions (photo thermal days) | 28.5 | 26.0 |
| SDPDV | Average seed per pod under standard growing conditions (#/pod) | 300.0 | 300.0 |
| PODUR | Time required for cultivar to reach final pod load under optimal conditions (photo thermal days) | 56.0 | 58.0 |
| THRSH | Threshing percentage. The maximum ratio of (seed/ (seed + shell) at maturity. Causes seed to stop growing as their dry weight increases until the shells are filled in a cohort. | 7.3 | 5.4 |
| SDPRO | Fraction protein in seeds (g (protein) g ⁻¹ (seed)) | 0.350 | 0.350 |
| SDLIP | Fraction oil in seeds (g(oil) g ⁻¹ (seed)) | 0.050 | 0.090 |



Table 2: Observed and predicted phenology, biomass, fruit yield and N uptake after calibration of CROPGRO-Tomato model

| Parameter | Simulated | Observed | RMSE | d-stat |
|--|-----------|----------|------|--------|
| V₁ (US 440) | | | | |
| Days to anthesis | 26 | 26 | 0 | 0.9 |
| Days to last picking | 103 | 103 | 0.7 | 0.9 |
| Biomass at maturity (kg ha ⁻¹) | 2310 | 2378 | 285 | 0.9 |
| Fruit yield (kg ha ⁻¹) (DW) | 1510 | 1439 | 545 | 0.7 |
| Nitrogen uptake (kg ha ⁻¹) | 41 | 38 | 6 | 0.9 |
| V₂ (TO-3251) | | | | |
| Days to anthesis | 26 | 26 | 0 | 0.9 |
| Days to last picking | 102 | 103 | 0.5 | 0.7 |
| Biomass at maturity (kg ha ⁻¹) | 1885 | 2302 | 435 | 0.8 |
| Fruit yield (kg ha ⁻¹) (DW) | 1286 | 1225 | 389 | 0.8 |
| Nitrogen uptake (kg ha ⁻¹) | 37 | 38 | 5 | 0.9 |

explained as under and the statistical indices were presented below.

3.3. Days to anthesis

Simulated value of days to anthesis was closer to the observed data, with RMSE value of 0.5 days, CRM value of -1 and NRMSE of 2%. This clearly showed that, CROPGRO-Tomato model overestimated the days to anthesis to the extent of 1%. However, under the present study simulation of days to anthesis was considered excellent as the normalized RMSE (NRMSE) value was less than 10% for both cultivars (Table 3).

3.4. Days to last picking

A difference of 2 days was noticed between observed and simulated values to attain the last picking for cultivar US 440 with RMSE, NRMSE and CRM values of 2 days, 2% and 1 day respectively, showed the tendency of the model to underestimate the days to the last picking by 1 day. For cultivar TO-3251 the difference of only 3 days was noticed between observed and simulated values to attain the last picking with RMSE, NRMSE and the CRM values of 3 days, 3% and 2 days respectively and this showed the tendency of the model to underestimate the days to last picking by 2 days. However, for both cultivars, the simulation was considered excellent with an NRMSE value of less than 10% (Table 4).

3.5. Biomass at maturity

The RMSE value of 570 kg ha⁻¹ reflected that the model

Table 3: Comparison of simulated and observed days to anthesis of tomato under different dates of planting and cultivars

| Treatment | Simulated | Observed | Difference |
|---------------------------------------|-----------|----------|------------|
| V₁ (US 440) | | | |
| D ₅ (11 th Aug) | 26 | 25 | 1 |
| D ₆ (23 rd Aug) | 27 | 27 | 0 |
| D ₇ (03 rd Sep) | 27 | 27 | 0 |
| D ₈ (13 th Sep) | 27 | 27 | 0 |
| RMSE | | 0.5 | |
| NRMSE | | 2 | |
| CRM | | -1 | |
| V₂ (TO-3251) | | | |
| D ₅ (11 th Aug) | 26 | 25 | 1 |
| D ₆ (23 rd Aug) | 27 | 27 | 0 |
| D ₇ (03 rd Sep) | 27 | 27 | 0 |
| D ₈ (13 th Sep) | 27 | 27 | 0 |
| RMSE | | 0.5 | |
| NRMSE | | 2 | |
| CRM | | -1 | |

Table 4: Comparison of simulated and observed days to the last picking of tomato under different dates of planting and cultivars

| Treatment | Simulated | Observed | Difference |
|---------------------------------------|-----------|----------|------------|
| V₁ (US 440) | | | |
| D ₅ (11 th Aug) | 102 | 102 | 0 |
| D ₆ (23 rd Aug) | 103 | 102 | 1 |
| D ₇ (03 rd Sep) | 101 | 104 | -3 |
| D ₈ (13 th Sep) | 105 | 106 | -1 |
| RMSE | | 2 | |
| NRMSE | | 2 | |
| CRM | | 1 | |
| V₂ (TO-3251) | | | |
| D ₅ (11 th Aug) | 100 | 102 | -2 |
| D ₆ (23 rd Aug) | 102 | 102 | 0 |
| D ₇ (03 rd Sep) | 100 | 104 | -4 |
| D ₈ (13 th Sep) | 103 | 106 | -3 |
| RMSE | | 3 | |
| NRMSE | | 3 | |
| CRM | | 2 | |

predicted above-ground biomass was quite good. The simulation of biomass at maturity stage was considered as fair with an NRMSE value of 25% for cultivar US 440 due to

overestimation of biomass by 16% with CRM value of -16% (Figure 1).

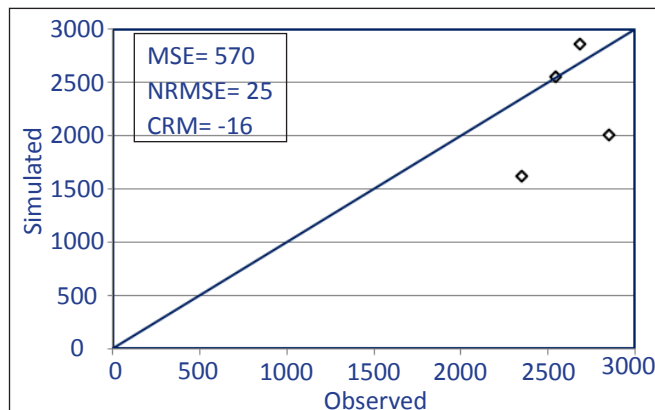


Figure 1: Simulated and observed biomass (kg ha^{-1}) of cultivar US 440 at first Picking phase using CROPGRO-Tomato model under different dates of planting

For cultivar TO-3251 the RMSE value of 519 kg ha^{-1} revealed that the model predicted the above-ground biomass was fair with an NRMSE value of 25%. This fair simulation was due to the underestimation of biomass by 3% with a CRM value of 3 (Figure 2). Similar results were reported by Sunil et al. (2006) from IARI with fair simulation between observed and simulated biomass. It might be due to the extensive data requirements and more sophisticated nature of the model.

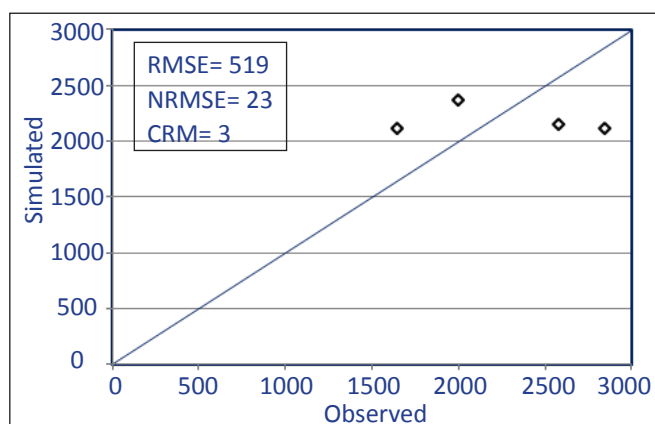


Figure 2: Simulated and observed biomass (kg ha^{-1}) of cultivar TO-3251 at first Picking phase using CROPGRO-Tomato model under different dates of planting

3.6. Fruit yield

Simulated fruit yield was varied with the observed data with an RMSE value of 771 kg ha^{-1} (dry weight). The simulation of fruit yield at the maturity stage was considered as poor with an NRMSE value of 59% for cultivar US 440 due to overestimation of the fruit yield by 46% with a CRM value of -46 (Figure 3).

In a similar way cultivar TO-3251 also showed the same trend with an RMSE value of 689 kg ha^{-1} (dry weight). Here also the simulation of fruit yield at maturity stage was considered as

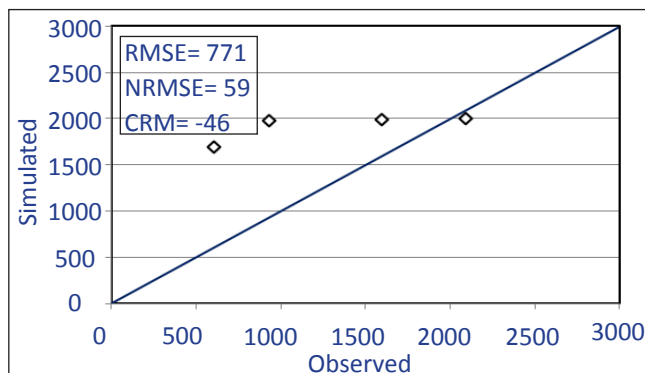


Figure 3: Simulated and observed fruit yield (kg ha^{-1}) of cultivar US 440 using CROPGRO-Tomato model under different dates of planting

poor with an NRMSE value of 56% due to overestimation of the fruit yield by 26% with a CRM value of -26 (Figure 4). Elsayedet al. (2017) from northeastern Italy also reported high RMSE values during validation of the CROPGRO-Tomato model.

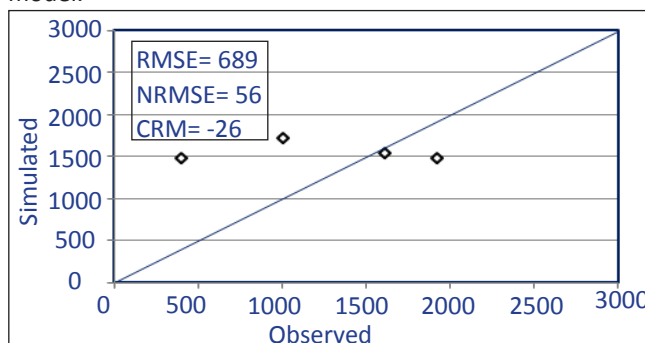


Figure 4: Simulated and observed fruit yield (kg ha^{-1}) of cultivar TO-3251 using CROPGRO-Tomato model under different dates of planting

3.7. Nitrogen uptake

Simulated nitrogen uptake was closely related to the observed data with an RMSE value of 18 kg ha^{-1} . The simulation of nitrogen uptake at the maturity stage was considered as poor with an NRMSE value of 49% for cultivar US 440 due to overestimation of the N uptake by 48% with a CRM value of -48 (Figure 5).

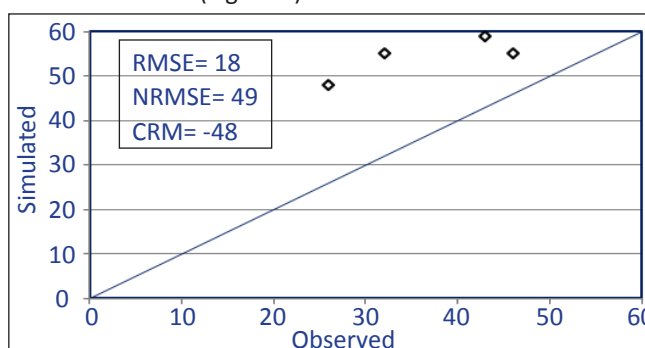


Figure 5: Simulated and observed N uptake (kg ha^{-1}) of cultivar US 440 at first Picking phase using CROPGRO-Tomato model under different dates of planting

Cultivar TO-3251 also showed a similar trend as that of US440 with an RMSE value of 15 kg ha⁻¹. Here also the simulation of nitrogen uptake at maturity stage was considered as poor with an NRMSE value of 39% due to overestimated the N uptake by 30% with a CRM value of -30 (Figure 6).

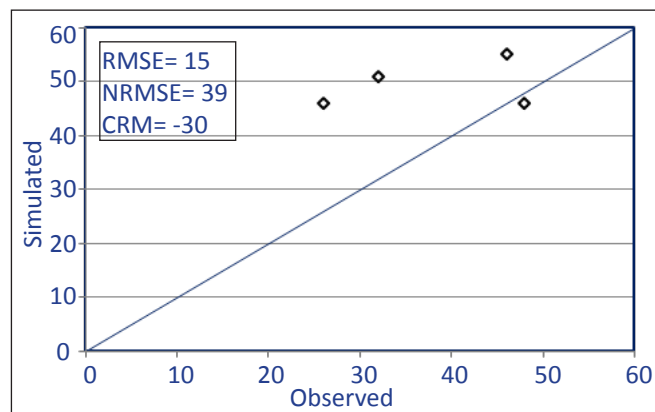


Figure 6: Simulated and observed N uptake (kg ha⁻¹) of cultivar TO-3251 at first Picking phase using CROPGRO-Tomato model under different dates of planting

4. Conclusion

Calibration of CROPGRO-Tomato model for days to anthesis, days to the last picking, dry matter production, fruit yield and N uptake for both cultivars was found reasonably good with low RMSE values and d-statistics value of ≥ 0.7 . Validation of the CROPGRO-Tomato model revealed that model performance was excellent with phenology, fair with dry matter production. Whereas it was poor with N uptake and total fruit yield for both cultivars as the model overestimation.

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