Evaluation of the CropSyst Model on Soybean (Glycine max L.) in the Tropics

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Abstract—South Sulawesi is one of the soybean producer provinces in Indonesia. As in other tropical areas, South Sulawesi season comprises dry and rainy seasons, so modeling of crops such as CropSyst can be very helpful in predicting planting time, providing irrigation, and applying the right fertilizer to get maximum soybean productivity. To apply the CropSyst model in the tropics such as South Sulawesi, calibration and validation of several plant parameters are required. Further calibration and validation results need to be tested to see the accuracy of predicting models. The results of soybean evaluation in South Sulawesi showed that RMSE (0.09 and 0.11), MBE (-0.01 and 0.11), MAE (0.08 and 0.11), and d (0.92 and 0.81) had values showing that CropSyst model accurately predicts the grain yield of soybean in South Sulawesi.

Keywords—soybean, CropSyst, calibration, validation, evaluation.

I. INTRODUCTION

CropSyst is a friendly crop simulation model used. The CropSyst model is used to look at the effects of climate, soil, and crop management systems on productivity and the environment. CropSyst simulates soil, nitrogen, plant growth and development, crop yields, residual production, soil erosion by water, and salinity [1]. The current developments that are heavily caused by the development of climate change will be a challenge for crop modeling to update the model [2]. Several studies have been done to see the level of accuracy of CropSyst model. Some of these studies suggest that CropSysts can predict convincingly the results of barley and irrigated rescue on plant yields [3], CropSyst models can be used as a means to regulate irrigation water to improve productivity with poor water quality [4], CropSyst model simulation with predictive climate can summarize the predicted outcomes going forward [5], calibration and validation of the CropSyst model for rice can precisely determine irrigation and proper fertilization [6], and evaluation of the CropSyst model on yields for cluster bean in India also shows the proximity between simulation and observation data [7].

South Sulawesi is a province in Indonesia, at 0°12' North Latitude - 8° South Latitude and 116°48' - 122°36' East Longitude. South Sulawesi which has an area of 46,083.94 km² divided into 21 districts and 3 cities. South Sulawesi is one of the soybean producer provinces in Indonesia, with an average productivity of 1.5 t ha⁻¹ grain yield [8].

II. MATERIAL AND METHOD

The research was conducted at Jenetaesa Village, Simbang Sub-district, Maros District which is one of soybean producer in South Sulawesi, Indonesia. This study used 2 varieties of soybeans that were Anjasmoro (90 days), and Argomulyo (80 days). The experiment was made by making a plot of 2 x 3 m with 3 replications. Fertilization is done with Ponska fertilizer (N 15%, P 15%, K 15%) dose 250 kg ha⁻¹ with irrigation 50 mm with interval every 10 days as much 8 times for Anjasmoro variety and 7 times for Argomulyo varieties. Other studies were conducted at Sawakong (Takalar District), Attangsalo (Soppeng District), and Liliriawang (Bone District) in the form of data collection of soybean productivity. Soil attributes at the research sites are presented in Table 1, while monthly rainfall data during 2016 is presented in Table 2.

### Table 1

<table>
<thead>
<tr>
<th>Districts</th>
<th>Sand</th>
<th>Clay</th>
<th>Silt</th>
<th>Bulk Density</th>
<th>Cation Exchange</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jenetaesa (Maros)</td>
<td>24</td>
<td>41</td>
<td>35</td>
<td>1.270</td>
<td>21.28</td>
<td>6.80</td>
</tr>
<tr>
<td>Sawakong (Takalar)</td>
<td>29</td>
<td>17</td>
<td>54</td>
<td>1.410</td>
<td>17.50</td>
<td>6.67</td>
</tr>
<tr>
<td>Attangsalo (Soppeng)</td>
<td>27</td>
<td>40</td>
<td>33</td>
<td>1.280</td>
<td>33.92</td>
<td>7.11</td>
</tr>
<tr>
<td>Liliriawang (Bone)</td>
<td>42</td>
<td>5</td>
<td>53</td>
<td>1.610</td>
<td>25.68</td>
<td>7.8</td>
</tr>
</tbody>
</table>
TABLE 2
MONTHLY RAINFALL IN THE YEAR 2016 AT FOUR RESEARCH LOCATIONS

<table>
<thead>
<tr>
<th>Districts</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan</td>
</tr>
<tr>
<td>Jenetaesa (Maros)</td>
<td>729</td>
</tr>
<tr>
<td>Sawakong (Takalar)</td>
<td>158</td>
</tr>
<tr>
<td>Attangsalo (Soppeng)</td>
<td>158</td>
</tr>
<tr>
<td>Liliriawang (Bone)</td>
<td>118</td>
</tr>
</tbody>
</table>

Treatment of irrigation is done every 10 days since sowing date with the amount of 50 mm for each time of administration. The irrigation interval along with the timetable and the amount of irrigation are presented in Table 3.

TABLE 3
MANAGEMENT IRRIGATION DURING RESEARCH

<table>
<thead>
<tr>
<th>Management</th>
<th>Anjasmoro</th>
<th>Argomulyo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Description</td>
<td>Quantity</td>
</tr>
<tr>
<td>Sowing date</td>
<td>7 August 2016</td>
<td></td>
</tr>
<tr>
<td>Line spacing (cm)</td>
<td>20 x 40</td>
<td></td>
</tr>
<tr>
<td>1st irrigation date</td>
<td>7 August 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2nd irrigation date</td>
<td>17 August 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>3rd irrigation date</td>
<td>27 August 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>4th irrigation date</td>
<td>6 September 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5th irrigation date</td>
<td>16 September 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>6th irrigation date</td>
<td>26 September 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>7th irrigation date</td>
<td>6 October 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>8th irrigation date</td>
<td>16 October 2016</td>
<td></td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Harvest date</td>
<td>4 November 2016</td>
<td></td>
</tr>
<tr>
<td>Total irrigation (mm)</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

For Calibration, data are used in research area at Maros District, while validation is done in 3 other locations, at Takalar, Soppeng, and Bone District with the same management. As for the evaluation of cropsyst model to see the relationship between the simulation with observation by statistically calculating Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Absolute Error (MAE), and Index of Agreement (d) [9], [10], [11].

\[
RMSE = \sqrt{\frac{1}{n} \sum (S - O)^2} \\
MBE = \frac{1}{n} \sum (S - O) \\
MAE = \frac{1}{n} \sum |S - O|
\]
\[ d = 1 - \frac{\sum(S-O)^2}{\sum(S-O)^2 + \sum(O-O)^2} \]  

explanation:

n = amount of data  
S = Simulation  
O = Observation

The evaluation was conducted to see if the CropSyst model can be applied to the research area for prediction. Evaluation of CropSyst model is done by performing calibration and validation on some parameters [12], [13], [14].

III. RESULTS AND DISCUSSION

3.1 Plant parameters for evaluation

For the purpose of the model, evaluation it is necessary to calibrate some aspects of crop varieties, that is in thermal time, phenology, transpiration, attainable growth, canopy growth, root, harvest, and senescence as in Table 4.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Anjasmo</th>
<th>Argomulyo</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal time accumulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base temperature(°C)</td>
<td>8</td>
<td>8</td>
<td>L</td>
</tr>
<tr>
<td>Cutoff temperature(°C)</td>
<td>25</td>
<td>25</td>
<td>L</td>
</tr>
<tr>
<td><strong>Phenology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree-days emergence (°C-days)</td>
<td>100</td>
<td>100</td>
<td>M</td>
</tr>
<tr>
<td>Degree-days begin flowering (°C-days)</td>
<td>760</td>
<td>720</td>
<td>M</td>
</tr>
<tr>
<td>Degree-days begin filling (°C-days)</td>
<td>1296</td>
<td>1235</td>
<td>M</td>
</tr>
<tr>
<td>Degree-days begin senescence (°C-days)</td>
<td>1622</td>
<td>1478</td>
<td>M</td>
</tr>
<tr>
<td>Degree-days maturity (°C-days)</td>
<td>1740</td>
<td>1563</td>
<td>M</td>
</tr>
<tr>
<td>Degree-days full senescence (°C-days)</td>
<td>1842</td>
<td>1641</td>
<td>M</td>
</tr>
<tr>
<td><strong>Transpiration</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy extinction coefficient for total solar radiation</td>
<td>0.5</td>
<td>0.5</td>
<td>L</td>
</tr>
<tr>
<td>Evapotranspiration crop coefficient at full canopy</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td>Leaf water potential at the onset of stomatal closure (J kg⁻¹)</td>
<td>-1,000</td>
<td>-1,000</td>
<td>D</td>
</tr>
<tr>
<td>Wilting leaf water potential (J kg⁻¹)</td>
<td>-1,500</td>
<td>-1,500</td>
<td>D</td>
</tr>
<tr>
<td>Maximum water uptake (mm d⁻¹)</td>
<td>10</td>
<td>10</td>
<td>L</td>
</tr>
<tr>
<td><strong>Attainable growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above ground biomass transpiration coefficient (kPa kg m⁻³)</td>
<td>5</td>
<td>5</td>
<td>L</td>
</tr>
<tr>
<td>Radiation use efficiency PAR (g MJ⁻¹)</td>
<td>2.5</td>
<td>2.5</td>
<td>C</td>
</tr>
<tr>
<td>Mean daily temperature (°C)</td>
<td>22</td>
<td>22</td>
<td>C</td>
</tr>
<tr>
<td><strong>Canopy growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific leaf area at optimum temperature (m² kg⁻¹)</td>
<td>28</td>
<td>28</td>
<td>C</td>
</tr>
<tr>
<td>Stem/leaf partition coefficient</td>
<td>3</td>
<td>3</td>
<td>L</td>
</tr>
<tr>
<td><strong>Root</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum root depth (m)</td>
<td>1.5</td>
<td>1.5</td>
<td>M</td>
</tr>
<tr>
<td><strong>Harvest</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstressed harvest index</td>
<td>0.3</td>
<td>0.3</td>
<td>M</td>
</tr>
<tr>
<td><strong>Senescence</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf area duration (°C-days)</td>
<td>900</td>
<td>900</td>
<td>L</td>
</tr>
</tbody>
</table>

C=Calibrated, D=Default, L=literature, M=Measured [15]
3.2 CropSyst Calibration

For calibration used data of plant parameters that have been got in research during 2016, especially grain yield. The difference between the simulation and observations result is minimized by a trial and error approach. After the grain yield results between the simulation and observation being closed, then next will be validated for each calibration results in some other areas. The results of the field research (observation) along with the simulated results from CropSyst models that have been calibrated are presented in Table 5.

<table>
<thead>
<tr>
<th>TABLE 5</th>
<th>OBSERVATION AND SIMULATION OF GRAIN YIELD CALIBRATION RESULT IN ANJASMORO AND ARGOMULYO VARIETIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean Varieties</td>
<td>Grain Yield (t ha(^{-1}))</td>
</tr>
<tr>
<td>Anjasmoro</td>
<td>1.86</td>
</tr>
<tr>
<td>Argomulyo</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Table 5 shows that in Anjasmoro variety the result of grain yield simulated is lower than the observation result, while in Argomulyo show the opposite is higher grain yield simulation compared with observation result.

3.3 CropSyst Validation

To validate the data that has been got from field research, thus calculation of the simulation results with the observation results in three other areas. This validation result will determine whether the model can accurately predict the grain yield of the soybean or not. Validation results in the three districts in South Sulawesi are presented in Table 6.

<table>
<thead>
<tr>
<th>TABLE 6</th>
<th>OBSERVATION AND SIMULATION OF GRAIN YIELD VALIDATION RESULT IN ANJASMORO AND ARGOMULYO VARIETIES IN SOUTH SULAWESI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Districts</td>
<td>Soybean Varieties</td>
</tr>
<tr>
<td>Takalar</td>
<td>Anjasmoro</td>
</tr>
<tr>
<td></td>
<td>Argomulyo</td>
</tr>
<tr>
<td>Soppeng</td>
<td>Anjasmoro</td>
</tr>
<tr>
<td></td>
<td>Argomulyo</td>
</tr>
<tr>
<td>Bone</td>
<td>Anjasmoro</td>
</tr>
<tr>
<td></td>
<td>Argomulyo</td>
</tr>
</tbody>
</table>

Table 6 shows that simulation results of Anjasmoro varieties in Takalar and Soppeng are lower than field observations, but in Bone District, the result of the simulation is higher than observation result. While for the Argomulyo variety, the simulation results are higher than the observations for the three districts.

3.4 CropSyst Evaluation

Evaluation of CropSyst model for Anjasmoro and Argomulyo varieties was done by calculating RMSE, MBE, MAE, and \(d\) from each variety. The results of statistical calculations for each variety are presented in Table 7.

<table>
<thead>
<tr>
<th>TABLE 7</th>
<th>EVALUATION PERFORMANCE CROPSYST MODEL ON GRAIN YIELD SOYBEAN IN SOUTH SULAWESI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean Varieties</td>
<td>Parameter</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Anjasmoro</td>
<td>Grain Yield (t ha(^{-1}))</td>
</tr>
<tr>
<td>Argomulyo</td>
<td>Grain Yield (t ha(^{-1}))</td>
</tr>
</tbody>
</table>
The results of the evaluation in Table 7 show that the RMSE (0.09 and 0.11) and MAE (0.08 and 0.11) are so small that the CropSyst model can accurately predict the productivity of both the research site and the validation sites. RMSE and MAE are two approaches to see the difference between simulation and observation [16, 17, 18]. MBE is used to view the simulated averages below or above observation. In Anjasomo MBE has a negative value, it shows that the simulation value is less than the observed value [19], while in Argomulyo is opposite. In the d (Index of Agreement) values show that both Anjasomo (0.92) and Argomulyo (0.81) have a value close to 1, showing that the CropSyst model is suitable [20] to applied in tropical regions such as South Sulawesi, Indonesia.

IV. CONCLUSION

The results of the evaluation on the grain yield of soybean show that CropSyst model has a tiny RMSE and MAE value (close to 0), thus accurately to predict the results of field research (observation). Thus it can be concluded that the CropSyst model accurately predicts grain yields in different regions of South Sulawesi, which have a tropical climate. So that, it can be concluded that the CropSyst model can be applied to tropical regions by doing calibration and validation.

REFERENCES


