AGRIVITA Journal of Agricultural Science. 2018. 40(3): 544-555

AGRIVITA
Journal of Agricultural Science

Preliminary Study of WOFOST Crop Simulation in Its Prospect for Soybean (*Glycine max* L.) Optimum Harvest Time and Yield Gap Analysis in East Java

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ARTICLE INFO

Keywords:
East Java
Harvest time
Soybean
WOFOST
Yield gap

Article History:
Received: February 13, 2018
Accepted: September 14, 2018

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ABSTRACT

Optimum harvest time and yield gap information are important aspects of grain quality optimization and production development. The World Food Studies (WOFOST) crop simulation model was studied in its application for soybean optimum harvest time and yield gap analysis in East Java, Indonesia. Data inputs were local weather of solar irradiance and daily temperature, with given soybean varieties provided in the WOFOST simulation. The simulation result was validated with the actual data using homogeneity test of regression coefficient. Result showed that differences between simulation and actual yield were insignificant (α=0.05), for each tested locations and soybean varieties. The average potential yield was 1,716 kg ha^{-1}, where the highest was obtained from S-France 904 variety located in Malang Regency. The optimum root mean square error was 49.42 kg ha^{-1} with correlation coefficient of 0.918. Meanwhile, the optimum harvest time and yield gap have corresponded to the actual data where harvest time was at the shortest in Blitar Regency using N-France 901 and N Spain 903 varieties, while the average yield gap was 33%. In conclusion, WOFOST simulation model has a prospect to be applied further using local soybean varieties followed by validation in the whole East Java region.

INTRODUCTION

The food security issue in the future will be much more concerned by the increase in the food demand. Various efforts have been conducted to increase the world food production by land extensification or either intensification to increase productivity. One of the intensive efforts that can be done is by optimizing the crop harvest time, where it is necessary as one of the parameters for yield optimization, reducing yield lost, and field production quality assurance to ease the post-harvest handling. Moreover, as a quantitative effort to assess the prospect of crop productivity improvement, the availability of a yield gap information of food crop will be necessarily needed to determine the potential development that can be done. Hence, the term yield gap has been introduced, where it refers to the difference of yield based on the actual farm or producer yield and potential production (Rattalino Edreira et al., 2017). In the food security issue, it is proper to define the yield gap as the percentage of the actual yield which refers to the increment of the world food production data which usually presented by the percentage from actual production (Fischer, 2015).

In Indonesia, beside rice as the main staple of the people, soybean is one of the food sources which significantly needed. In fact, its cultivation has to spread in corresponds to the demand which showed by statistics data of the soybean planting area in 2015 that reached 614,095 ha; with 963,183 t of production and the average yield of 1,417 t ha^{-1} in 2008 to 2012 (Statistics Indonesia, 2017). Meanwhile, according to Koentjoro, Sitanggang, & Makarim (2015), the soybean yield gap in which shown by the prospect of soybean development in East Java as one of soybean production center reached 0.58 t ha^{-1} in 2014. With the diversity of the potential agro-ecological zone in the whole Indonesian region, the yield gap prediction in every location in Indonesia considered different in specific.

ISSN: 0126-0537 Accredited by DIKTI Decree No: 60/E/KPT/2016

Cite this as: Abadi, F. R., Tastra, I. K., & Koentjoro, B. S. (2018). Preliminary study of WOFOST crop simulation in its prospect for soybean (*Glycine max* L.) optimum harvest time and yield gap analysis in East Java. *AGRIVITA Journal of Agricultural Science, 40*(3), 544–555. http://doi.org/10.17503/agrivita.v40i3.1832

This may demand a comprehensive research with its consequence of the availability of suitable tool to support the soybean yield gap analysis where the information resulted is needed in the soybean yield development in Indonesia.

One of the tools that can be used in the optimum harvest time and yield gap analysis is a simulation models (Grassini et al., 2015) which mostly are based on crop growth or development and potential crop yield. On the national scale, a simulation model development is necessarily needed to support the acceleration and precision in the decision support system. The application of simulation models has been developed to comply the need for yield, potential and production prediction system which conducted in more effective and precise. Hence, the appropriate and reliable data of soybean production is obviously needed to measure the amount of national import to guarantee supply which fit with the demand of a certain commodity in the country (Tastra, Koentjoro, & Abadi, 2017). In addition, to achieve a successful system approach, innovation has to be made (Pound & Conroy, 2017) which supported by building a system of science, a system of government and a system of market where the science system providing viable knowledges, that encouraged by precise assessment with advance technology applications.

Until now, there are simulation models of potential crop yield which have been developed and have its prospect to be utilized for yield gap analysis. For instance, based on the crop growth model of Simple and Universal Crop Growth Simulator (SUCROS) that developed in a particular algorithm with concise code (Zhang et al., 2008). Tastra, Erliana, & Fatah (2012) had been developing simulation model of soybean national self-sufficiency, which employed available statistical data. Salmerón & Purcell (2016) used DSSAT-CROPGRO soybean model to analyze soybean phenology which may describe its potential yield. Meanwhile, Setiyono et al. (2010) assessed the application of SOYSIM for a simulation model of soybean growth and yield within its optimum condition. And furthermore, complying the development of the information technology, computer hardware and software also the internet, SUCROS.SIM which had rewritten in Powersim software (SUCROS.SIM) by Koentjoro, Sitanggang, & Makarim (2015) was continued to be re-written in the WEB based simulation model (SUCSOY.INS) (Tastra, Koentjoro, & Abadi, 2017). By employing the WEB networking facilities, the simulation model can be easily accessed and it is possible to be developed by many experts to improve its application.

Meanwhile, the WOFOST or The World Food Studies is a simulation model of crop growth (Kroes & Supit, 2011) which may dynamically simulate crop growth or to predict potential crop production (de Wit et al., 2015). Hereinafter, WOFOST model has been developed in many locations for various crops, and applications. Likewise that had been done by Eweys, Elwan, & Borham (2017) that employed WOFOST to simulate growth of maize, Gilardelli et al. (2016) for rapeseed flower and Huang et al. (2015) for wheat. The physiological status that performed in the simulation may also be used to perform crop stress analysis (Jin, Liu, Wu, & Liu, 2015), while a yield potential. The parameters that used in the WOFOST model includes climate; crop characteristics and soil type. By climatic and crop parameter inputs, the WOFOST model can accommodate Indonesian region which spreads from 6^{o} N to 11^{o} South latitude in different agro-ecological zone and potential yield performance with various local soybean varieties. The WOFOST application also handy to be used which using the user interface that possible to simulate inputs dynamically that may support to achieve a reliable prediction of potential crop development. Therefore, the aim of this research was to study the prospect of the WOFOST crop simulation model application for optimum harvest time and soybean yield gap analysis using parameters that refers to Indonesian region especially East Java province.

MATERIALS AND METHODS

The research was conducted at the System Dynamic laboratory of the Indonesian legume and Tuber Crops Research Institute (ILETRI), Malang, East Java, Indonesia from December 2017 to February 2018. It was a desktop study using the WOFOST ver. 7.1.7 with WOFOST Control Centre (WCC) ver. 2.1.2 of computer crop simulation model software of the Wageningen University, Netherland. The consecutive procedure for the study followed the flow chart diagram in Fig. 1.

From the diagram in Fig. 1, initially the WOFOST program in WCC was started and the potential crop growth was chosen for potential yield analysis and then began to input the data parameters. The parameters were used as input and analysis in the WOFOST application were soybean crop, weather data, and timer set, while the soil parameters were not used for the potential crop production analysis and left remained with its given set. The timer set the start day in a fixed emergence date on 210 of Julian date (Koentjoro, Sitanggang, & Makarim, 2015). Overall, the weather data were obtained from the weather stations located in three regencies namely: Malang, Blitar and Probolinggo with each measured geographical location (Table 1). The location parameters were latitude, longitude and altitude, while the Angstrom coefficient was set to minus indicated that radiation was measured (Boogaard, Wolf, Supit, Niemeyer, & van Ittersum, 2013). It was depended on its availability in each weather station where in fact that the daily solar irradiance in Watt m^{-2} that obtained from Karangploso weather station was used for irradiation data of East java in 2008-2012. While other weather data which was the temperature maximum and minimum in °C, was obtained from three weather station site locations.

While the crop parameter was the soybean variety, which was using four varieties namely: N-France 901; C-France 902; N-Spain 903; and S-France 904. All varieties came with given crop parameters in the WOFOST software. In the process, a soybean variety was chosen for the simulation and then consecutively for the other varieties.

After all parameters which required were set, then the application was to be run (simulated) using WCC user interface where resulted the concerned simulation output namely: potential yield in final weight of living storage organs (WSO) in kg ha^{-1} that derived the yield gap (WSO-actual yield in kg ha^{-1}) (Koentjoro, Sitanggang, & Makarim, 2015); and the simulated harvest time in DAY ended or HALT which referred to the optimum harvest time for each variety and year. Simulation in every year from 2008 to 2012 was conducted by using reruns facilities in the WOFOST user interface (WCC). Data resulted from the simulation were analyzed using the homogeneity test of linier regression coefficient (*b*) by comparing t or F calculation ($t_{cal.}$ or $F_{cal.}$) with t critical ($t_{tab.}$ or $F_{tab.}$), also the analysis of variance. While the validation trial also described the root mean square error (RMSE) as residual based measures (Bellocchi, Rivington, Donatelli, & Matthews, 2011), which performed the comparison of the resulted simulation with the actual statistical data. If the homogeneity test result showed insignificant, then the analysis was continued with validation with the actual statistical data in East Java.

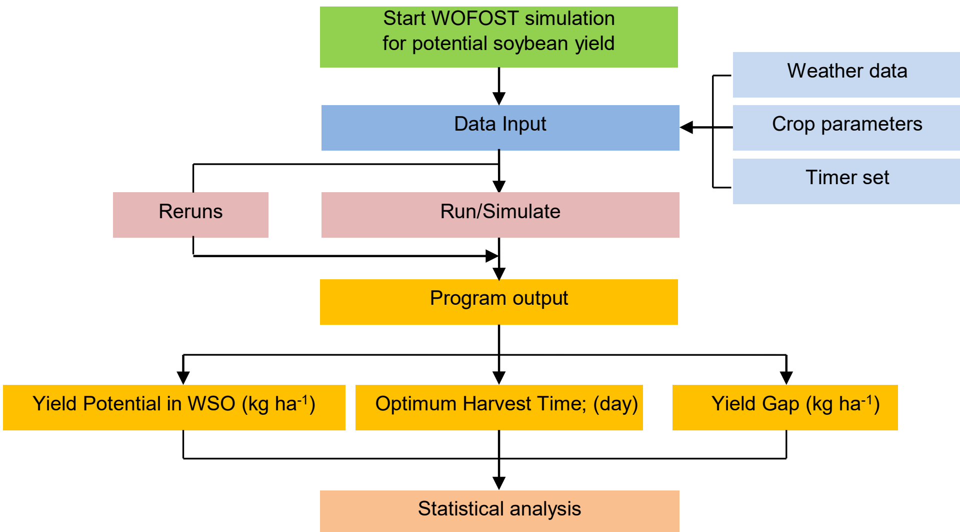


Fig. 1. Flow chart procedure of the WOFOST study using local weather data parameters

Table 1. Weather data site locations and data availability

Regency	Weather Station	Latitude	Longitude	Altitude (asl*)	Available data
Malang	Karangploso	07°45’48” S	111°35’48” E	600	2008-2012
Blitar	Wlingi water dam	08°08’36” S	111°52’24” E	174	2008-2012
Probolinggo	Muneng	07°55’00” S	111°22’00” E	10	2009-2012

Remarks: *Above sea level

RESULTS AND DISCUSSION

The study result showed the performance of the WOFOST simulation model analysis described the soybean yield performance during 2008-2012 in accordance with the available weather data obtained (1). The WOFOST simulation model has a various output that may concerned, where the soybean crop potential in weight of storage organs (WSO) was investigated as an important factor to be analyzed (2), followed by the optimum harvest time (3) and yield gap analysis (4) that mainly discussed.

Local Weather Input

The main specific local input parameter which used in the WOFOST simulation was the weather data. It included the solar irradiance that was obtained from the weather station site at Karangploso District, Malang Regency of the Meteorological, Climatological, and Geophysical Agency, represented the average solar irradiance in East Java during 2008-2012. The annual average daily solar irradiance was 553 + 23.68 W m^{-2} (Fig. 2) appropriated with observed value by Ugwuoke & Okeke (2012) which ranged from 426 to 773 W m^{-2}. This data derived the solar radiation that referred to the solar energy per unit area over time in the WOFOST program. Hence, the solar radiation was used as a variable to describe the sensitivity of the WOFOST simulation to produce the WSO of each soybean varieties.

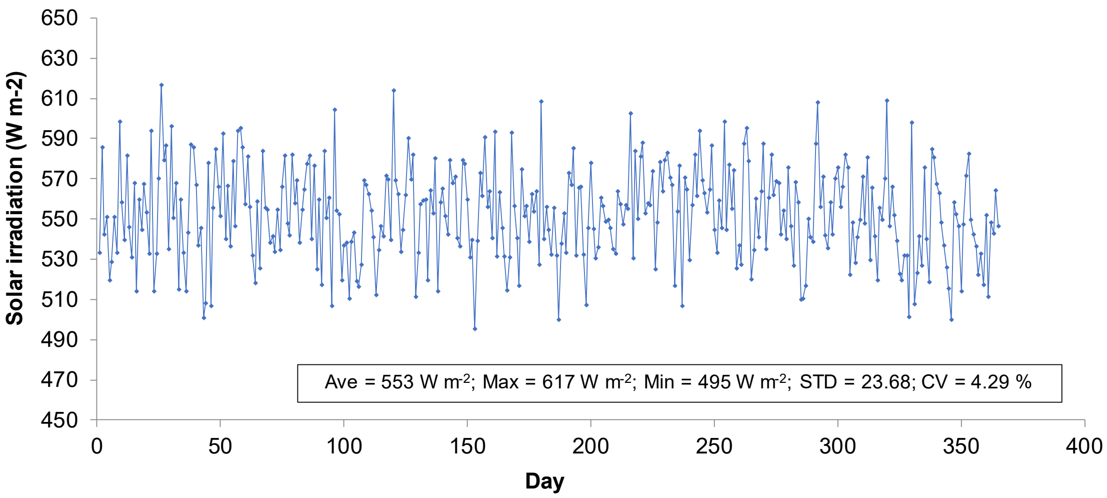


Fig. 2. Average annual daily solar irradiance in 2008 – 2012 of East Java, obtained from weather station of Karangploso

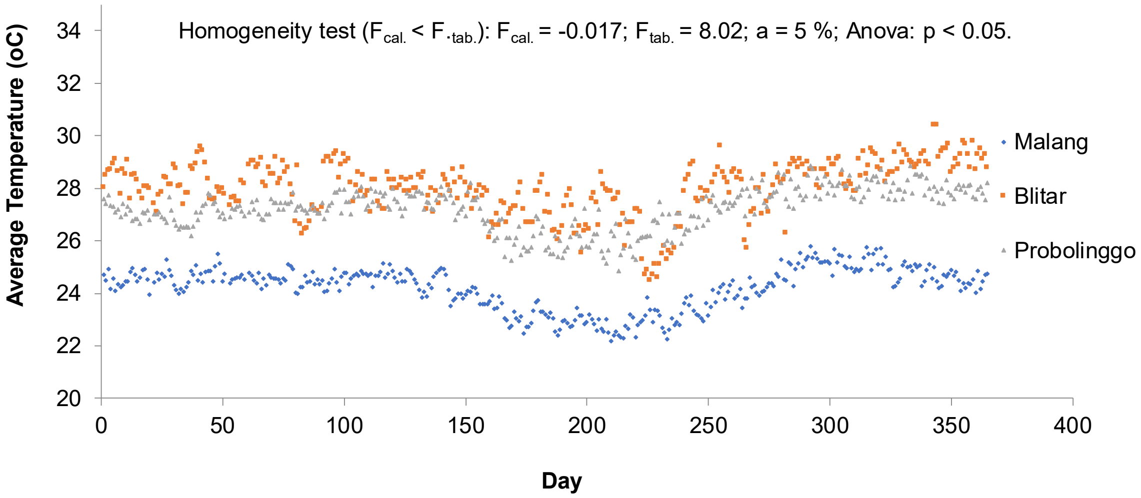
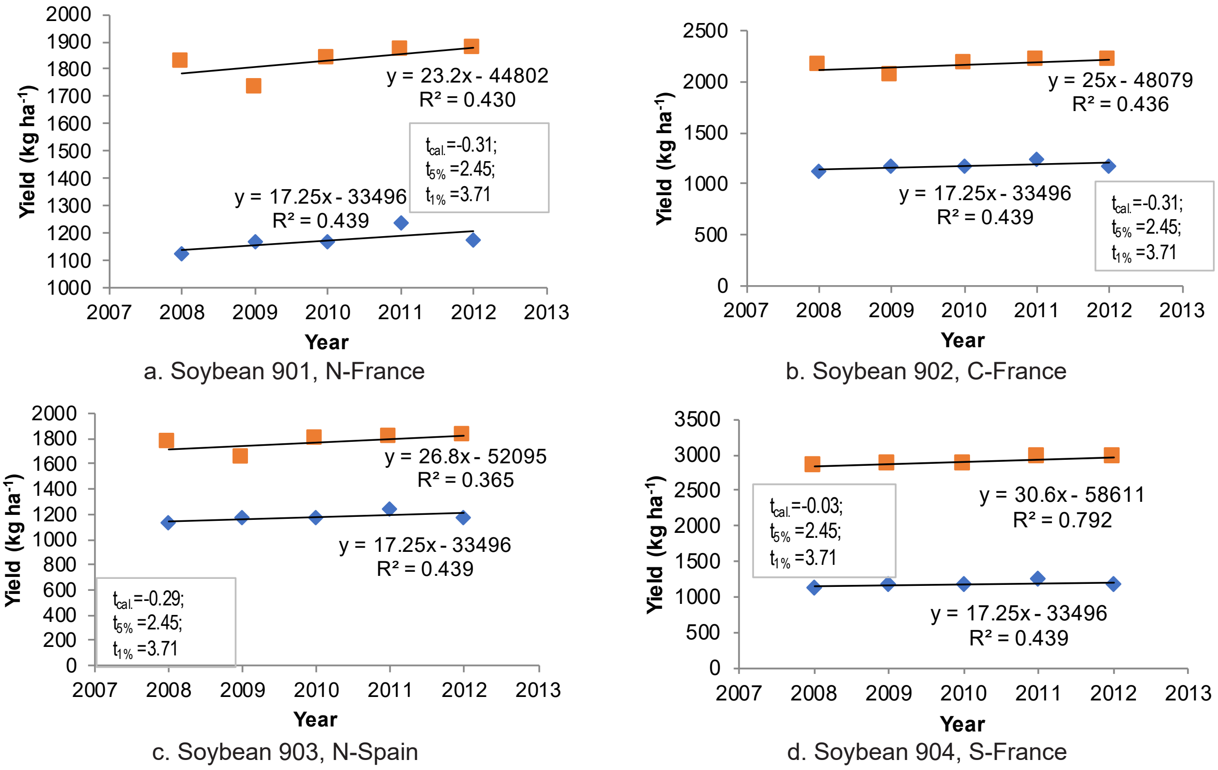


Fig. 3. Average daily temperature (°C) in 2008-2012 of Malang, Blitar and Probolinggo Regencies, obtained from local each weather stations



Remarks:
- Legend ◆: Actual
■: Simulation
- Actual data obtained from the average yield of soybean in Malang Regency.
- Weather station coordinate: 7°45’48” S and 111°35’48” E

Fig. 4. The soybean yield potential using given varieties in the WOFOST application and weather data of Malang Regency compared with the actual data in 2008-2012

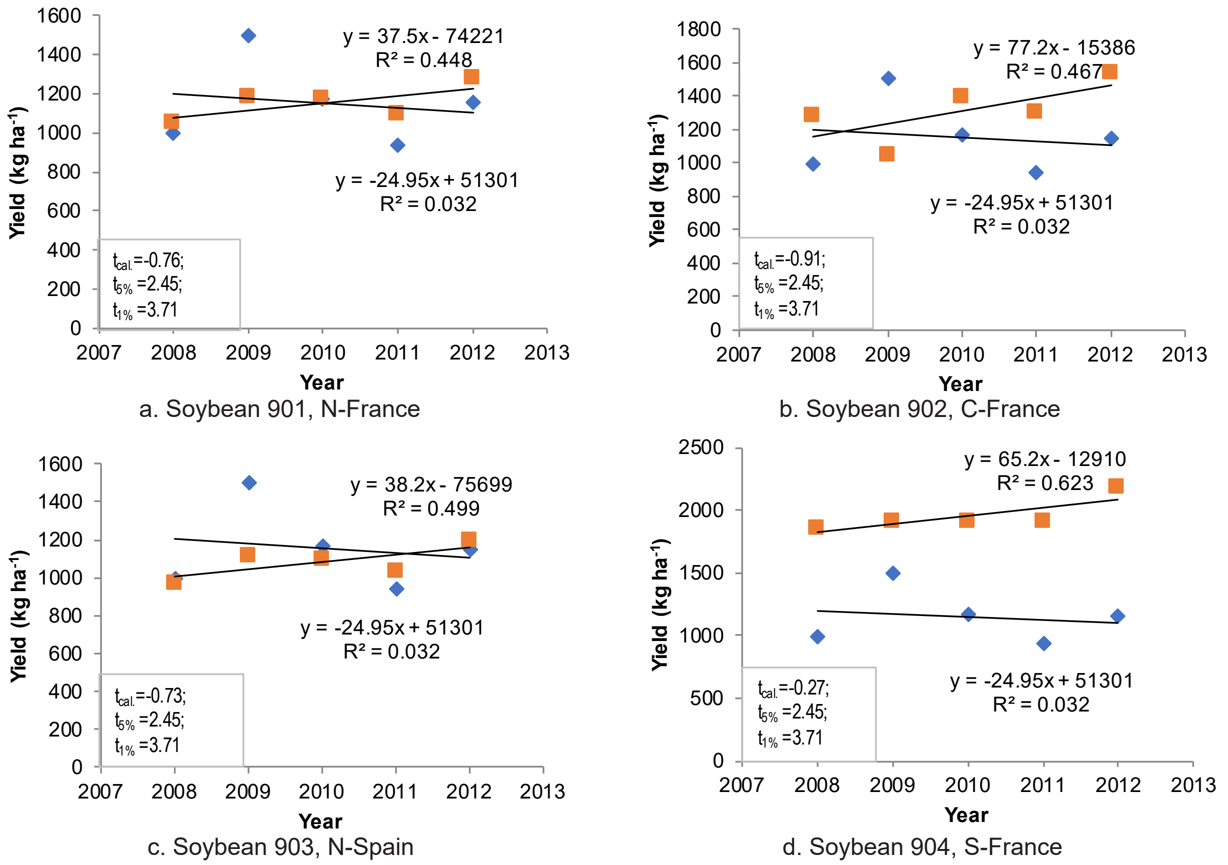
Meanwhile, the minimum and maximum temperature data was obtained from three weather stations namely Malang, Blitar and Probolinggo Regencies. The average daily temperature which was derived from the average daily minimum and maximum temperature pattern showed that the overall pattern of the average temperature in 2008-2012 was homogeny ($F_{cal.}$<$F_{tab.}$) at 5% level where the $F_{cal.}$ was -2.03 and $F_{tab.}$ was 8.02 (Fig. 3). While the variance test showed that all the daily average temperature for each location were different significantly ($p<0.05$). These showed that the locations affect the daily average temperature which then became variables in the WOFOST simulation.

Potential Soybean Yield

The potential crop yields were resulted from the WOFOST simulation in final WSO using weather data of Malang, Blitar and Probolinggo Regencies. All WSO resulted for each given soybean varieties were showed homogeny where $t_{cal.}$<t_{tab} at 5% and 1 % levels. Although there was no identified significant pattern, the homogeneity test showed no significant different of the overall slope (*b*) between the simulation and actual data.

The weather station of Malang located on 07°45’48” S and 111°35’48” E with the altitude of 600 asl was administratively located in Ngijo village, Karangploso District of Malang Regency, East Java Province (Table 1). The homogeneity test of potential yield and the actual data showed insignificant different (Fig. 4).

The weather station of Blitar located on 08°08’36” S and 111°52’24” E with the altitude of 174 asl was administratively included in Wlingi village, Wlingi District of Blitar Regency (Table 1). The homogeneity test of potential yield and the actual data showed insignificant different (Fig. 5).



Remarks:
- Legend ◆: Actual
  ■: Simulation
- Actual data obtained from the average yield of soybean in Malang Regency.
- Weather station coordinate: 8°8'36" S and 111°52'24" E

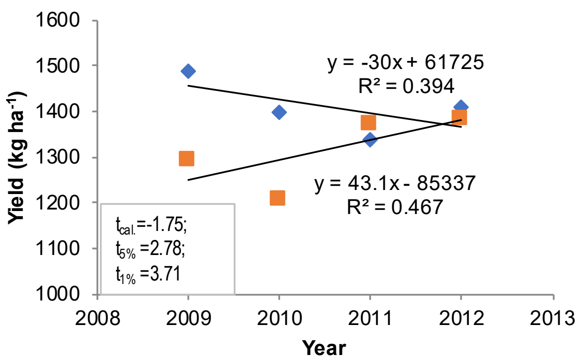
Fig. 5. The potential soybean yield using given varieties in the WOFOST application and weather data of Malang Regency compared with the actual data in 2008-2012

The weather station of Blitar located on 08°08'36" S and 111°52'24" E with the altitude of 174 asl was administratively included in Wlingi village, Wlingi District of Blitar Regency (Table 1). The homogeneity test of potential yield and the actual data showed insignificant different (Fig. 5).

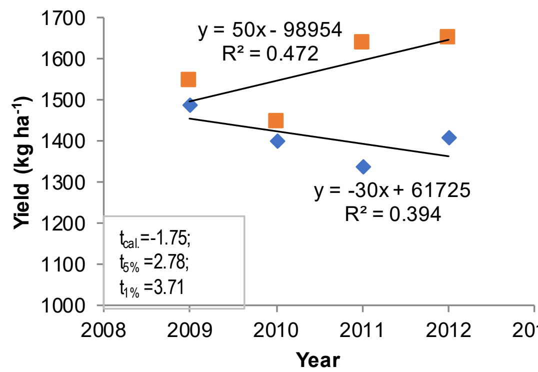
Meanwhile, the weather station site Probolinggo regency was located on 07°55'00" S and 111°22'00" E with the altitude of 10 asl, which administratively included in Muneng village, Sumberasih District of Probolinggo Regency (Table 1). The homogeneity test of potential yield and the actual data showed insignificant different (Fig. 6).

The simulation result showed that the highest average yield gained from S-France 904 variety in Malang Regency that reached 2,895 kg ha^{-1}, while the lowest average yield was from Spain 903 variety in Blitar Regency of 1,083 kg ha^{-1}. Likewise in overall, the highest average yield was obtained from S-France 904 variety of 2,357 kg ha^{-1} (Y_v), located in Malang regency that reached 2,167 kg ha^{-1} (Y_l). Moreover, the overall average potential yield was 1,716 kg ha^{-1} (Table 2). The analysis of variance showed significant difference in potential yield among locations and varieties, where the highest potential yield was gained from S-France 904 variety in Malang regency. The difference among varieties thought to be an absolute mean when the genetic factors which stick to each variety effected to the potential yield, while difference yield in each location may occur when weather data variable caused by different ecology, geographical locations and other anomalies. Different location in each degree of latitude (7-8°) represents the area coverage of around 111 km of distance. While other factors may affect is the altitude, where this was showed by the difference in potential yield in Malang that higher than Blitar and Probolinggo which was different significantly. All those variables were used in the WOFOST simulation.

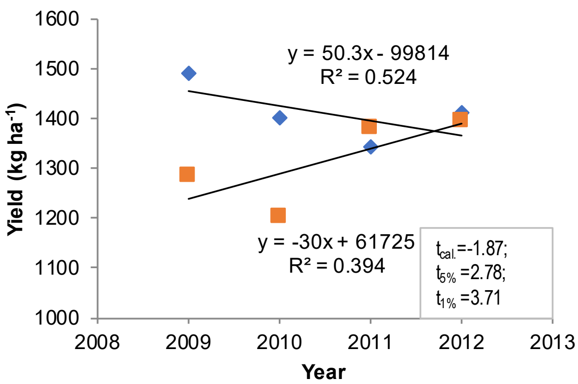
From above data obtained, although there was no clear pattern regarding the correlation between the simulation result and the actual data, it was proven by statistical evidence that all the simulation results were showed insignificantly different with the actual data of Malang, Blitar and Probolinggo Regency. These can be affected by input data which was used given crop parameters that available in the WOFOST Application (Fig. 4 and Fig. 5). By considering soybean as a homogeneous type of crop (*Glycine max* L.), this occurrence may be a promising method to be utilized for Indonesian soybean. In addition, the potential yield resulted from the WOFOST simulation was corresponded with the average yield of Indonesian soybean varieties which ranged from 790 to 3,890 kg ha^{-1} (Balitkabi, 2016). These showed that the resulted variations from the WOFOST simulation were still fairly reasonable and can be studied more by validation in the Indonesian region. Furthermore, the prospect of the WOFOST model can be resulted in wider variations, when it is using detail crop parameters, weather and soil type of Indonesian agro-ecology.



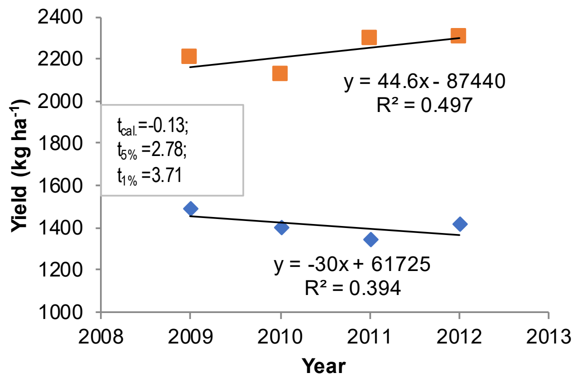
a. Soybean 901, N-France



b. Soybean 902, C-France



c. Soybean 903, N-Spain



d. Soybean 904, S-France

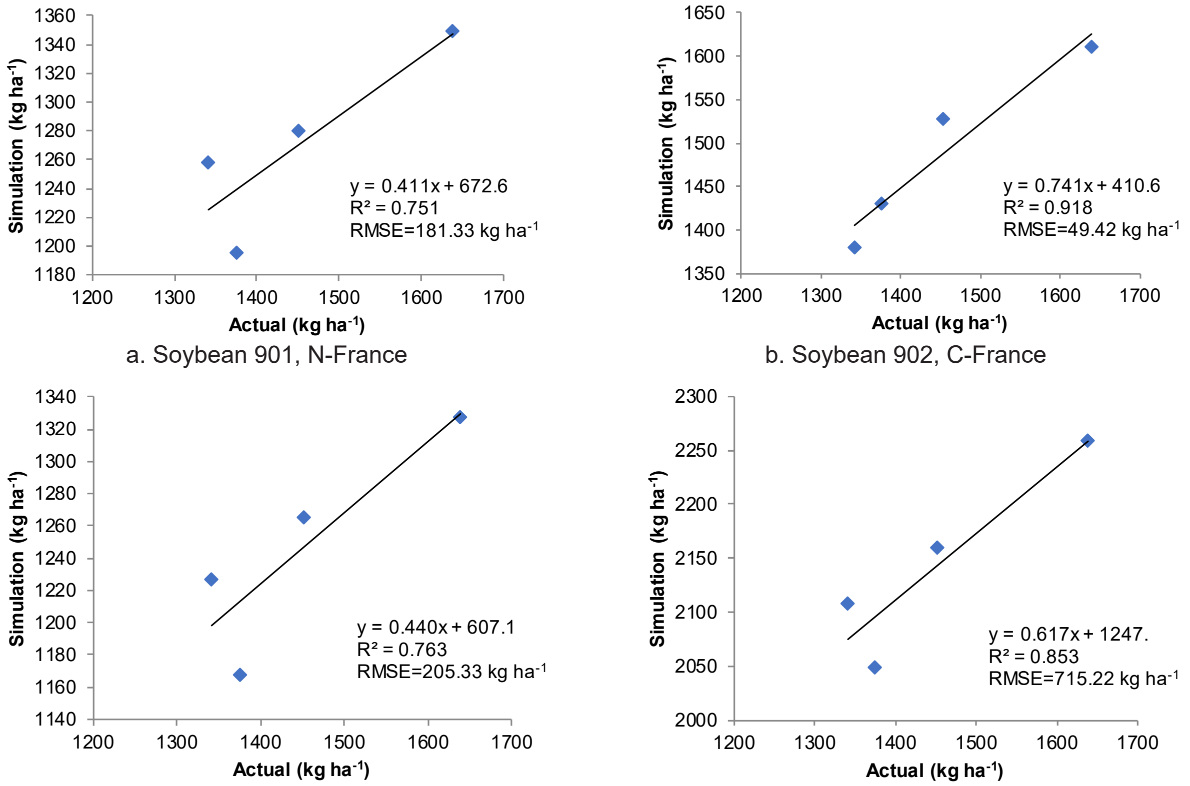
Remarks:
- Legend ◆: Actual
  ■: Simulation
- Actual data obtained from the average yield of soybean in Malang Regency.
- Weather station coordinate: 7°55'0" S and 112°22'10" E

Fig. 6. The potential soybean yield using given varieties in the WOFOST application and weather data of Probolinggo Regency compared with the actual data in 2008-2012

Table 2. Homogeneity test of the simulation result and actual data of average soybean yield in 2008-2012

Soybean Variety	Malang ($t_{5\%}$=2.45)			Blitar ($t_{5\%}$=2.45)			Probolinggo ($t_{5\%}$=2.78)			Y_v
	Average yield (kg ha^{-1})		$t_{cal.}$	Average yield (kg ha^{-1})		$t_{cal.}$	Average yield (kg ha^{-1})		$t_{cal.}$	
	WOFOST	Actual		WOFOST	Actual		WOFOST	Actual		
N-France 901	1830	1176	-0.31	1154	1152	-0.76	1316	1410	-1.75	1433^{bc}
C-France 902	2171	1176	-0.31	1310	1152	-0.91	1571	1410	-1.75	1684^{b}
N-Spain 903	1773	1176	-0.29	1083	1152	-0.73	1314	1410	-1.87	1390^{c}
S-France 904	2895	1176	-0.03	1948	1152	-0.27	2228	1410	-0.13	2357^{a}
Y_l	2167^{a}			1373^{b}			1607^{b}			1716

Remarks: Mean values within a column followed by the same letters are not significantly different at p<0.05 according to Duncan's Multiple Range Test; Y_v = Average potential yield for each soybean varieties (kg ha^{-1}); Y_l =Average potential yield for each location (kg ha^{-1})



a. Soybean 901, N-France
b. Soybean 902, C-France
c. Soybean 903, N-Spain
d. Soybean 904, S-France

Fig. 7. WOFOST simulation result correlation based on available weather data with the average actual statistics data of Soybean yield in East Java during 2009-2012

Table 3. Optimum harvest time (Day) from the WOFOST simulation for each given varieties and locations

Soybean Variety	Optimum Harvest Time (Day)				
	N-France 901	C-France 902	N-Spain 903	S-France 904	Average
Malang	74	79	74	96	80^{a}
Blitar	61	66	61	80	67^{b}
Probolinggo	61	66	62	81	68^{b}
Average	65^{b}	70^{b}	65^{b}	85^{a}	72

Remarks: Mean values within a column followed by the same letters are not significantly different at p<0.05 according to Duncan's Multiple Range Test

Table 4. Yield gap resulted from the WOFOST simulation for each variety and location

Location	Yield Gap (kg ha^{-1})					(%)*
	N-France 901	C-France 902	N-Spain 903	S-France 904	Average	
Malang	654	995	597	1719	991[a]	70
Blitar	2	158	-69**	796	222[a]	16
Probolingo	-94**	162	-96**	818	197[a]	14
Average	187 [b]	438 [b]	144[b]	1111[a]	470	33
(%)	13	31	10	78	33	

Remarks: Mean values within a column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's Multiple Range Test; * = actual average soybean yield of East Java in 2008-2012 was 1417 kg ha^{-1}; ** = simulation less than actual

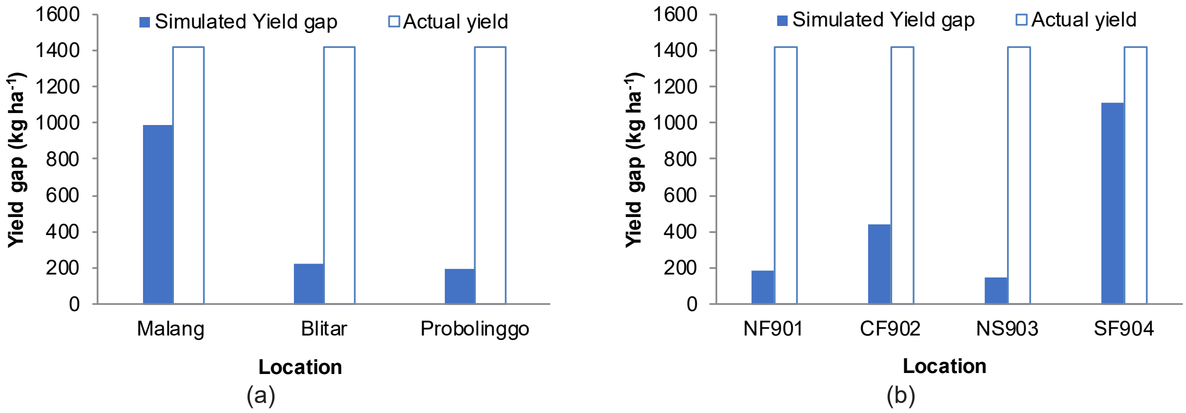


Fig. 8. The simulated soybean yield gap for each location (a) and variety (b), which resulted from the WOFOST simulation with the actual average soybean yield of East Java during 2008-2012

Based on the previous homogeneity test in three regencies namely: Malang, Blitar and Probolinggo, the overall simulation result was then compared with the actual statistics data of soybean yield in overall East Java. Data showed that the actual yield data in 2009-2012 were consecutively: 1,342; 1,375; 1,452; 1,639 kg ha^{-1} (Statistics Indonesia, 2017). In accordance, the highest regression coefficient (R^2) was found on C-France 902 variety of 0.918 and the lowest was on N-France 901 variety of 0.751 (Fig. 7). Strong correlation with high R^2 indicates the high validity of the simulation model. Although this was a preliminary study phase, the correlation indicated the high prospect for the application of the WOFOST simulation model as presented in a reliable validation in a given location in East Java and moreover it can be calibrated for all Indonesian or East Java regions. Meanwhile, the lowest RMSE was showed on C-France 902 variety of 49.42 kg ha^{-1} which thought to affirm the strong correlation resulted. The highest RMSE was showed on S-France 904 variety of 715.22 kg ha^{-1}. Since the RMSE shows the average error obtained for the given data, the desired RMSE for the model validation is the lower one. The higher value in the correlation and RMSE might be improved in further wider data exploration in further validation of the model and furthermore when it is considering all the detailed parameters in the WOFOST simulation.

Optimum Harvest Time

The optimum harvest time was obtained from the WOFOST output in the HALT parameter which showed the time reached at the final soybean development stage (DVS). The shortest harvest time was found at 61 days while the longest was found at 96 days, while the average of all was found at 72 days. The average harvest time was found at longest on S-France 904 variety (85 days), while the shortest was on N-France 901 and N Spain 903 (65 days). Moreover, the average optimum harvest time based on location was at the longest in Malang Regency (85 days), while the shortest was in Blitar regency (67 days). The analysis of variance showed significant difference on S-France 904 variety with the other three varieties, while location was also different significantly at Malang with Blitar and Probolinggo in another group (Table 3). In addition, a soybean variety with short age can reduce the production cost, and when it is combined with the high productivity characteristic, it will be the expected in most.

Overall, the optimum harvest time resulted from the WOFOST simulation corresponded to the average harvest time of the Indonesian soybean varieties which ranges from 66 to 110 days (Balitkabi, 2016). The soybean optimum harvest time refers to its maturity level that affected by variety (Mourtzinis, Gaspar, Naeve, & Conley, 2017; Poerwoko, 2016; Wegerer, Popp, Hu, & Purcell, 2015) and altitude (Smidt, Conley, Zhu, & Arriaga, 2016). The soybean varieties that used were adaptive from European region which may caused in its adaptive performance in the simulation due to their respective crop parameters especially the assimilate partitioning inputs namely: fraction of total dry matter to root (FRTB); fraction of above ground dry matter to leave (FLTB); fraction of above ground dry matter to stem (FSTB); and the fraction of above ground dry matter to storage organ (FOTB).

Yield Gap

The yield gap generally derived from the potential yield were ranged from 197 to 991 kg/ha or about 14 to 70% of the average yield in East Java in each selected location, while there were ranged from 144 to 1111 kg/ha or about 10 to 78% of average East Java production for each variety. The overall yield gap was 470 kg/ha or about 33% of the average yield in East Java (Table 4; Fig. 8) which was slightly lower than had informed by Koentjoro, Sitanggang, & Makarim (2015), that reached 580 kg/ha. The analysis of variance showed that the yield gap did not differ significantly in a different location, while the yield gap of S-France 904 variety was different significantly from other varieties.

There were found negative value of the yield gap resulted from the WOFOST simulation which may occur because of the crop parameters variations that affected the simulation result of potential production. In further study or analysis, it has to be concerned regarding to the primary data source that obtained must be validated especially by field experiment. The reliability of the simulation is depending on the validity of parameter inputs. Nevertheless, the utilization of the given soybean varieties in the WOFOST application may describe the ability of those soybean varieties to be cultivated in the tropical region especially in East Java, Indonesia.

The prospect of the soybean development can be evaluated based on the yield gap analysis and considering various parameters including the location and soybean variety that can produce optimum yield. According to the simulation result, the potential soybean development in Malang Regency was seemingly higher than other tested location, while the in fact that altitude of the Malang regency specifically at the weather station is considered higher with specific weather pattern that temperature may lower. This can have occurred when the varieties that used were originated from European adapted region which located in sub-tropical to temperate region with the average lower solar radiation and temperature. With those weather characteristics close to the original source location, Malang regency could be the appropriate location to do the field test for the given soybean varieties in the simulation. Moreover, based on the study, the most prospective soybean variety among other tested varieties was the S-France 904. Even tough, the application of this variety in the tropical region such as Indonesia especially East Java needs to be assessed or furthermore it will require a comprehensive breeding experiment. Judging from the study result, the WOFOST crop simulation with its facilities provided in dynamic optional parameters and scientific based program structure produced fairly reasonable output that can be further investigated. The application of WOFOST crop simulation can be a prospective method to perform the soybean optimum harvest time and yield gap analysis in East Java. Therefore, there will be needed to be studied regarding the application of the WOFOST simulation which supported by field experiment using local parameters including soybean varieties, local weather and soil.

CONCLUSION AND SUGGESTION

From the study, it can be concluded that the WOFOST simulation result showed insignificant different with the actual yield ($t_{cal.}<t_{tab.}$; α=0.05) for each tested locations and given soybean varieties. The optimum root mean square error was 49.42 kg ha^{-1} with the correlation coefficient of 0.918. The study indicated that the optimum harvest time and yield gap simulation analysis has a prospect to be conducted in the WOFOST application that can be further investigated. Therefore, it was suggested to

validate the WOFOST simulation model using local soybean varieties.

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