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Modeling and Simulation of Oil Palm Plantation Productivity Based on Land Quality and Climate Using Artificial Neural Network

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ABSTRACT

Crop growth and production on particular land and climate is strongly influenced by the interaction between plants, climate, soil, and management. Land quality and climate which greatly affect the expected production of oil palm are soil type, soil depth, altitude, soil pH, rainfall year^{-1}, average temperature, water deficit in mm year^{-1}, air humidity, and solar radiation. Oil palm production as a function of land quality and climate can be predicted using various methods, one of them is artificial neural network (ANN). This study used the algorithm backpropagation ANN method. The aim of this research was to develop a prediction model of oil palm plantation productivity based on land quality and climate and simulate the effect of climate change on oil palm productivity. The result showed that water deficit and average temperature had negative correlation to the productivity of oil palm plantations, while sun shine duration, relative humidity and annual rainfall had positive correlation with the productivity of oil palm plantations. Through the optimization procedure obtained the best ANN architecture is 12 neurons in input layer, 3 neurons in the hidden layer and 1 neuron in the output layer, the best model obtained at 30 000 iterations on training step with a value of determination coefficient (R^2): 0.98 and Root Mean Square Error (RMSE): 0.49, while on the test step obtained the value of R^2: 0.94 and RMSE: 1.63. The results of simulation showed that the simultaneous influence of climate changes i.e. decreasing the rainfall quantity of 100 mm year^{-1}, 1 °C temperature rise, and increasing water deficit 50 mm year^{-1} reduced the productivity of oil palm plantations by 2 tons ha^{-1} year^{-1}. It can be concluded that ANN can be used to predict the production of palm oil based on land quality and local climate with very good results and we can predict the effect of climate change on the yield of oil palm.

Keywords: ANN architecture, climate change, palm oil yield

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INTRODUCTION

The productivity of oil palm plantations is strongly influenced by soil quality and climate, among others: soil type, soil depth, height, soil pH, rainfall, average temperature, water deficit (mm year^{-1}), air humidity, and solar radiation. Productivity of oil palm plantations ranged from 13 (ton h^{-1} year^{-1}) fresh fruit bunches (FFB) on less suitable land to more than 24 (ton h^{-1} year^{-1}) FFB on suitable land (Sianturi 1993).

Oil palm plantation productivity is a very important factor to guide the decision-making process in the future. Knowing this importance, the Malaysian Palm Oil Board (MPOB) has long been interested in forecasting its crude palm oil (CPO) production (Abdullah 2003).

Weather is one of the key components that controls crop yield. It affects plant growth and development, particularly at critical crop growth stages, that may reduce yield significantly (Kartika *et al*. 2016). It is well known that one of the main factors causing yield to change from year to year is the climate variability as no two growing seasons experience exactly the same weather (Lobell & Burkeb 2010).

Neural network prediction method is one of the most advanced approaches, especially for prediction involving many parameters that work simultaneously with nonlinear functional forms of relationship. Artificial neural network (ANN) is a computational structure that was developed based on the process of biological neural systems in the brain tissue. ANN is a translation of the functions of the human brain (biological neurons) in the form of a mathematical function that is able to process parallel computation (Ashish 2002). ANN has received a great deal of attention because it can treat complicated problems especially if the data are imprecise (Kartika *et al*. 2016).

Meanwhile Pham (1995) stated that the neural network is flexible in inputting data and producing response. A network consisting of multilayers may become the perfect solution for a variety of performances. ANN learning can complete parallel computation for complex tasks, such as prediction and modeling; classification and pattern recognition; clustering, and optimization. According to Petterson (1996) multilayer feed forward back propagation ANN comprises three layers namely the input layer, hidden layer and output layer. The input layer has n nodes, the hidden layer has h nodes and the output layer has m nodes. Back propagation neural network architecture is presented in Figure 1.

The use of the ANN method is expected to give a better answer in predicting plantation crop production as a function of land quality and climate parameters. The non-linear nature of neural networks is an advantage that can overcome the shortcomings of the conventional methods

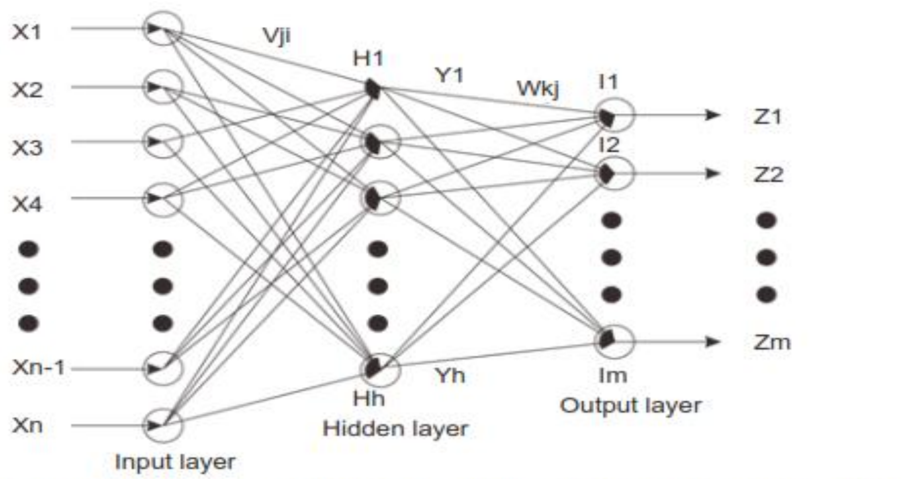

Figure 1 Illustration multilayer feed forward back propagation artificial neural network models.

that are complicated and do not function well when entering a non-linear model.

The purpose of the study is to predict the productivity of oil palm plantations and determine the effect of climate change on productivity using ANN. Some climate elements are simulated to see the simultaneous effect of climate change on theivity of oil palm plantations.

MATERIALS AND METHODS

The materials used in this study were data production, soil quality and climate. Secondary data were collected from several oil palm plantations in Riau and Kalimantan Provinces. Soil samples were taken from some of the plantations and analyzed in the laboratory to complete the soil fertility data. The palm oil production was predicted using the ANN model based on land quality and climate. The input layer of soil quality and climate were as follows: soil type, soil depth, height, soil pH, rainfall, average temperature, water deficit (mm year^{-1}), air humidity, and solar radiation. The target or output layer was oil palm productivity.

The first stage was to perform optimization studies to obtain the best ANN models in predicting the productivity of oil palm plantations. Optimization of ANN models was done through the steps of learning (training) and testing. The training step is a learning process of unsupervised neural networks to find the best value of weighting factor (w). The method used for the training was back propagation algorithm. In this algorithm the network weights were modified by minimizing the sum of squared errors against all the output vertices. The testing step is a method to test the weighting acquired during training. Testing was conducted to see the consistency of the best model obtained during training by using different input data.

The summary of the process of back propagation neural network algorithm into a computer programming language is as follows: a Input pair of data, output targets and training parameters; b Normalization of data input and output targets; c Providing initial value of weighted; d Repeating training for each data pairs (covering steps: Calculation of the value of activation, Calculation error, Calculation error gradient, until all the data pairs werecounted); e Calculation of total gradient error; f Correction (adjustment) weighting; and g Termination when training criteria was reached.

Simulations were carried out to determine the effect of simultaneous changes of several elements of climate such as rainfall, temperature and water deficit on the productivity of oil palm plantations. The best phase of ANN model simulations were executed using hypothetical data input. The ANN program was written using Delphi 6 programming language. The reliability of the ANN model is shown with the value of coefficient of determination (R^2) and root mean square error (RMSE) of output data. The ANN simulation interface is presented in Figure 2.

RESULTS AND DISCUSSION

Relations between climate parameters and productivity of oil palm plantations based on the data collected could be analyzed in a single relationship between parameters and productivity as follows: water deficit and average temperatures was negatively correlated with the productivity of oil palm plantations. This is in accordance with the statement of Caliman (1998) that the dry months can decrease the production of palm oil, for example in Lampung and Palembang in which a water deficit of 100 mm could reduce the yield by 8-10% in the first year and 3-4% in the second year. The effect of drought stress not only occurs in the vegetative phase but also in the generative phase (Pimentel *et al*. 1999).

Length of solar radiation, relative humidity and rainfall were positively correlated with

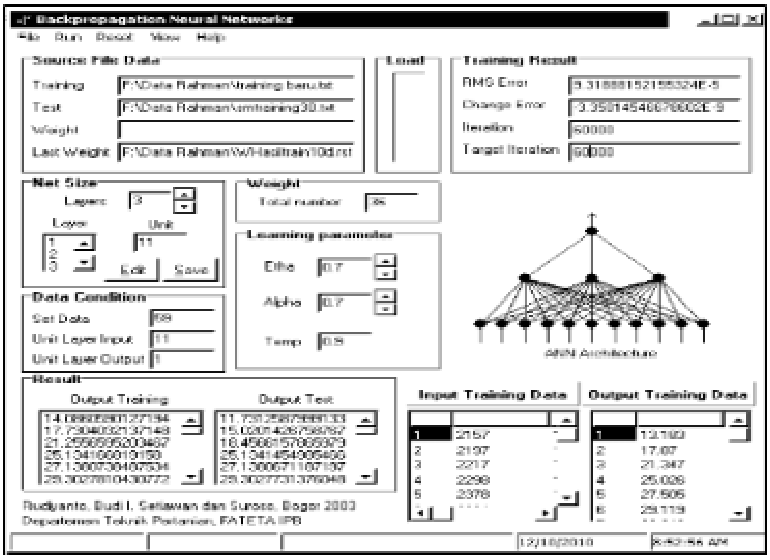

Figure 2 Interface of artificial neural network simulator.

productivity of oil palm plantations.This is in line with observations by Martoyo *et al*. (1983) that the average relative humidity should be at least 75%; at the time of seeding, the air relative humidity should ideally range between 80-90% and a length of sunshine duration of 5-7 hours day^{-1} (Lubis 1992). Observations show that the growth of oil palm in North Sumatra is better than that in Africa because the region has a high radiation and rainfall that generally occurs at night, so it does not reduce the solar radiation (Sianturi 1993).

Optimization ANN models has been done through training and testing. In the training phase as many as 59 data pairs of land quality and climate with oil palm productivity and 15 pairs of test phases from different locations were used. The optimization process was done by simulating the number of hidden layers that is 3,5,7, and 10. The results of optimization are presented in Table 1.

In the results obtained from the training phase of the ANN models, the best architecture was: 15 nodes input layer-3 nodes in hidden layer- and 1 node output layer, as presented in Figure 3.

A comparison between the 3-hidden layers and other hidden layers (5,7, and 10) in the training stage showed that the 3 hidden layers is the best model. The

Table 1 Optimization results of some artificial neural network models

No	Model	R^2	RMSE
1	15-3-1	0.99	0.494
2	15-5-1	0.95	1,027
3	15-7-1	0.95	1.026
4	15-10-1	0.96	1.293

architecture is 15 (input layers) 3 (hidden layers)–1 (output layer) with the highest R^2 and RMSE smallest. Meanwhile a higher number of hidden layers does not produce a better ANN model.

The reliability of the model is shown in the graphical analysis between the actual and predicted with coefficient determination (R^2) values of: 0.99 and RMSE: 0.494 in training phase. In the testing phase this model was consistent with R^2 of 0.90 and RMSE 1.63. A graph of the reliability of the ANN model to predict the productivity of oil palm plantations is presented in Figure 4.

Determination ofthe effect of climate change on land productivity has been carried out by simulating the hypothetical data from 3 plantation locations. The data used were a reduction in rainfall of 100 mm year^{-1}, increasing the average temperature of 1 °C,

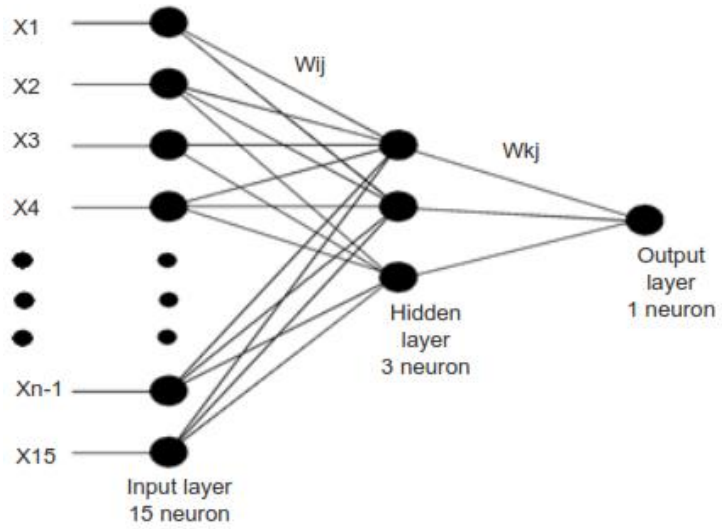

Figure 3 The architecture of the best artificial neural network model.

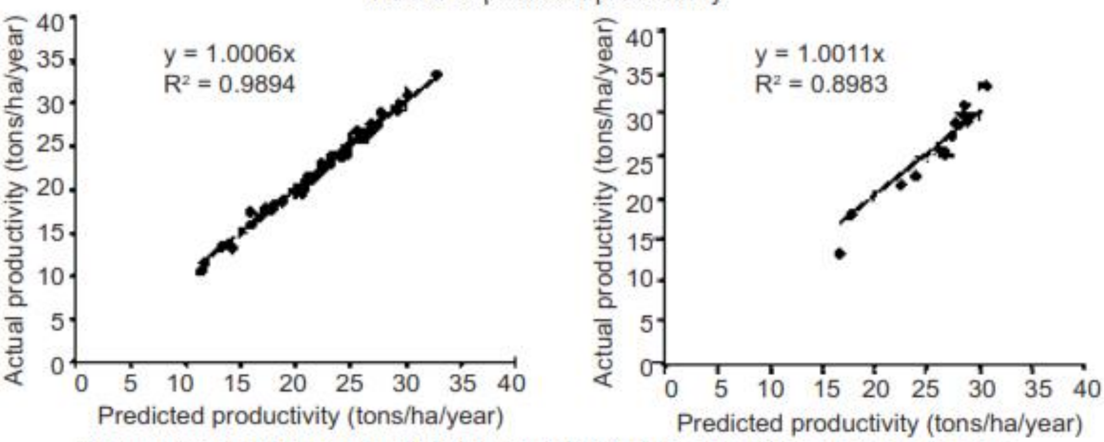

Figure 4 Calibration model artificial neural network on training and testing phase.

and increasing water deficit of 50 mm year^{-1}. Simulation results showed that the influence of climate change of the three elements simultaneously caused a decrease in the average production forecast of 2:15 tons ha^{-1} year^{-1}.

The effect of climate change on plantation productivity is presented in Figure 5. If, rainfall and temperature increase in the coming few years, our simulation using the ANN model is: increased rainfall data of 100 mm year^{-1}, 1 °C temperature rise, and reduced water deficit of 100 mm year^{-1}, would result in increased mean productivity of 3.23 tons ha^{-1} year^{-1}. Whereas increased rainfall 200 mm year^{-1}, 1 °C temperature rise, and reduced water deficit by 100 mm year^{-1} will simultaneously result in an increase in mean productivity of 4.88 tons ha^{-1} year^{-1}.

CONCLUSION

Artificial neural networks were able to simultaneously predict the productivity of oil palm plantations based on several elements of the soil and climate. A reduction in rainfall of 100 mm year^{-1}, an increase in the average temperature of 1 °C, and an increase in water deficit of 50 mm year^{-1} simultaneously caused a decrease in palm oil production by an average of 2.15 tons ha^{-1} year^{-1}. Increased rainfall of 100 mm year^{-1}, increased t temperature of 1 °C, and the reduction of water deficit of 100 mm

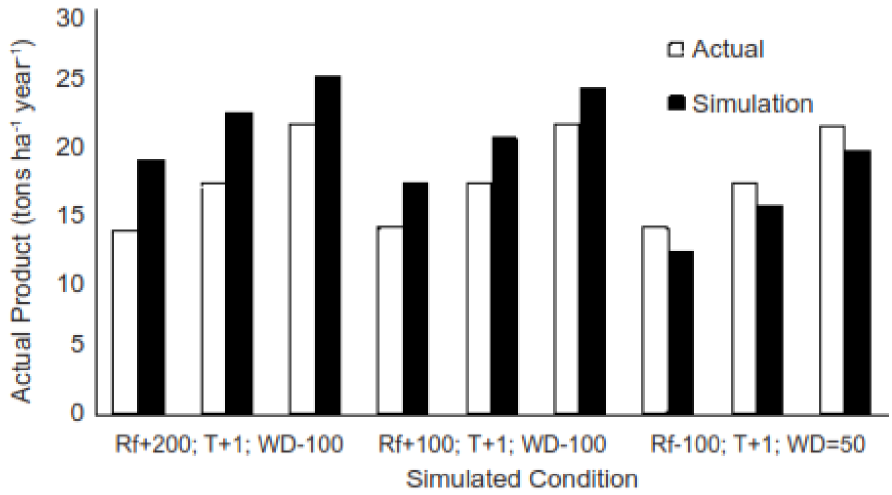

Figure 5 The effect of climate change to palm oil production.

year^{-1} will increase the oil production by 3.23 tons ha^{-1} year^{-1}.

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