THE CONSTRUCTION OF MATHEMATICAL MODEL BETWEEN POPULATION OF *Piezodorusrubrofasciatus*AND SOYBEAN POD DAMAGE FOR SUPPORTING FOOD SAFETY AND INTEGRATED PEST MANAGEMENT*)

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ABSTRACT

The aims of this research are: (a) to predict the damage of soybean pod through the mathematical model of relationship between population density of *P. rubrofasciatus* and pod damage, (b) to predict the soybean yield through the mathematical model of relationship between population density of *P. rubrofasciatus* and pod damage where made by modification of Reynolds Transport Theorem (RTT). This research was used Completely Randomized Design with nine treatments and each was replicated three times. The treatments were: P0 = control, P1 = 1 nymph, P2 = 2 nymphs, P3 = 3 nymphs, P4 = 4 nymphs, P5 = 1 adult, P6 = 2 adults, P7 = 3 adults, and P8 = 4 adults. The population density of pod sucking bug was the independent variable, while dependent variables were: rate of pod damage, and dry pod weigh. Analysis of mathematical modeling was made by approaching of Continuum Theory and Reynolds Transport Theorem. The results showed that (1) Relationship between population of *P. rubrofasciatus* and pod damages in the form of mathematical model which is used to predict the soybean pod damage has error 0,02 – 0,10 %, and (2) Mathematical model where made by modification of RTT which is used to predict the soybean yield has error 0,023– 0,099 %.

Key words: P. rubrofasciatus, Mathematical Model, Pod damage, soybean yield

INTRODUCTION

Soybean (*Glycine max (L.)* Merrill) are important legume crops, besides having a high nutritional content (protein 40.8%, 17.9% fat, and carbohydrate 38.5%), soybean is also a raw material for large industries such as soybean oil, soybean milk, and soybean sauce (Adisarwanto, 2005).

Green Ladybug considered pests polyphag and eat various parts of plants. Attacks on soybean plants begin to look at the age of 51 days after transplanting (DAT). Damage to pods and seeds due to pest attack can reach 51.7% (Sukarno and Tengkano, 1979). Damage to pods begin to happen when first pods are formed, then the damage has increased and peaked at 56

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days old soybean plants with the level of damage by 30.42% (Susilo, 1993). Due to the attack of this pest, the pod and seed flat, fall peas, wrinkled seed, black seed rot, a black spot on the seed, or seed holes, and due to further grow the seed will decrease (Tengkano, M. Faith, and AM Tohir, 1992).

An effort to increase production of soybeans, many common limiting factors. One of the obstacles that cause soybean yield is low due to pest attack (Marwoto, Wahyuni, and Neering, 1991). Arifin (1997) said there are nine types of major pest that attacks soybean plants, and one of them is considered important is *P. rubrofasciatus*. Measures to control pod-sucking pests, especially in central soybean production are still relying on insecticides, but has not succeeded very well and yield losses are still quite high (Marwoto, Suharsono, and Supriyatin, 1999).

Knowledge about the effect of damage by pests to the quality and quantity of results is required as input to make decisions in Integrated Pest Management (IPM). The pattern of relationship between the sensitivity of plants against damage and yield losses due to pest attack is a pattern of relationships between the components of complex ecosystems, complex and dynamic.If the pattern of these relationships have been known to be used to determine the exact time when the application of insecticides to prevent yield losses due to pest attack (Rauf, 1991).

Given the complexity of the composition and ecosystem interactions to facilitate the required analysis models that can describe the actual state of the ecosystem. According to Noordwijk and Lusiana (2006), the model is a simple translation of various forms of relationships and interactions between components in a system. When the shape of this relationship is well known, it can be compiled into a mathematical equation to describe the various assumptions that exist. Usefulness of this model in pest management is very important and widely used to control several important pests, especially in developed countries, but in Indonesia until now still not been developed.

For the purposes of prediction analysis of yield losses, several researchers attempted to quantitative influence pest populations against crop damage and yield. Quantitative these developments have encouraged the experts to formulate the relationship between pest population and the damage, and yield losses caused by constructing a mathematical model (Headley, 1972; Hammord and Pedigo, 1982). One method that can be used to analyze the relationship between pest populations and crop damage, is a mathematical model of Reynolds Transport Theorem (Munson, et al., 1998). This study aims: (1) to estimate the extent of damage due to pest attacks soybean pod *P. rubrofasciatus* by using mathematical models derived from mathematical equations Reynolds Transport Theorem, and (2) The mathematical model of the relationship of insect pest populations *P. rubrofasciatus*with pod damage will be used to predict soybean yield.

MATERIALS AND METHODS

Research using Completely Randomized Design (CRD) with nine kinds of treatment and repeated three times. Type of treatment intended to be P0 = Control, P1 = Inoculation 1 nymph, P2 = 2 nymph, P3 = 3 nymph, P4 = 4 nymph, P5 = 1 head of adult, P6 = 2 adults, P7 = 3 adults, and P8 = 4 adults. The study was conducted on June through to November 2012. To estimate the number of pods damaged by the attack of *P. rubrofaciatus*, then the observed data are: the number of damaged pods (attacked by*P. rubrofasciatus*). As for the suspect soybean yield prediction based on the number of damaged pods, the observed data are: wet weight of pods. Nymph and adult inoculation into the cage done at age 54 HST (grain filling stage R5-6). To estimate the damage of pod attack by *P. rubrofasciataus* was used Continuum Theory approach (Apsley, 2005) and mathematical equations Reynolds Transport Theorem (Munson, et al., 1998) as follows: The rate of change inside the control volume (CV) + net outward flux through surface of the control volume = The rate production of the source inside the control volume.

$$\frac{D}{Dt}\left[\text{number of pods attacked}\right] = \frac{\text{number of insectsin the CV}}{time} \text{..........(1)}$$

Equation (1) can be expressed in mathematical form as following :

$$\frac{\partial}{\partial t}\int_{cv} \rho\, dV + \int_{cs} \rho\, v.\hat{n}\, dA = \frac{\text{number of insectsin CV}}{time} \text{ .... (2)}$$

where $\rho =$ pod density in the CV per unit volume. While v = speeds insect entry / exit (through control surface or CS) into CV to attack the pods, and $\hat{n}$ = unit vector of the CS andperpendicular to the surface of CS. While A =surface area of CS, where insects enter and exit, by assuming that (a) velocity direction parallel to the normal insects from entering the field, (b)area A has only one normal vector), mean area A of a plane. Next equation (2) can be resolved into:

$$\frac{\partial}{\partial t}\left[\underbrace{\rho \int dV}_{CV}\right] + \rho\, v.\hat{n} \int_{cs} dA = \frac{\text{number of insect in CV}}{time} \quad \text{.............} \ (3)$$

Or can be write,

$$\frac{\partial}{\partial t}\left(\underbrace{\rho V}_{CV}\right) + \underbrace{\rho v.\hat{n} A}_{CS} = \frac{\text{number of insect in CV}}{time} \quad \text{................} \ (4)$$

Since V in Equation (4) is the volume of CV andthe amount of which is assumed to constant the amount (do not change with time), the equation can then be written

$$\underbrace{\rho\frac{\partial V}{\partial t} + \frac{V\,\partial \rho}{\partial t}}_{CV} + \underbrace{\rho\, v.\hat{n} A}_{CS} = \frac{\text{number of insect in CV}}{time} \text{..............} \ (5)$$

if the equation is derived, value $\frac{\partial V}{\partial t}$ = 0,so that equation (5)turn into :

$$V\frac{\partial \rho}{\partial t} + \underbrace{\rho v.\hat{n} A}_{CS} = \frac{\text{number of insect in CV}}{time} \quad \text{.......................} \quad (6)$$

based on the principle of Reynolds Transport Theorem (Munson, *et al*., 1998), so that to speed the insects 'go' through CS coded – (negative), while to speed the insects out through CS, coded + (positive), so equation (6) furtherwill turn into:

$$V\frac{\partial \rho}{\partial t} - \underbrace{\rho v.\hat{n} A}_{in} + \underbrace{\rho v.\hat{n} A}_{out} = \frac{\text{number of insect in CV}}{time} \text{...........} \ (7)$$

From the equation (7) can further be seen that $v\,.\,\hat{n}$ = speed the insects 'go' through CS, amount equal to the rate of change in the number of pods on the CV to receive an attack, expressed by $\frac{\partial Z}{\partial t}$, so the equation (7) turn into:

$$V\frac{\partial \rho}{\partial t} - \underbrace{\rho A\frac{\partial Z}{\partial t}}_{in} + \underbrace{\rho A\frac{\partial Z}{\partial t}}_{out} = \frac{\text{number of insect in CV}}{time} \quad \text{.........} \ (8)$$

Where:

V = CV (control volume), where insect attack (P x L x T) = (0,70 x 0,60 x 0,60) x 1 m^3 = 0,25 m^3.

A = The surface area of CS (control surface) to one side where the insects attack and exit (P x L x 1 m^2 = 0,70 x 0,60 = 0,42 m^2)

ρ = Pod density in the CV be attacked

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$\frac{\partial Z}{\partial t}$ = The rate of change in the number of pods attacked per unit time

In = is the number of pods to be attacked.
Out = is the number of pods after being attacked.

Furthermore, mathematical models will be used to estimate number of pods damaged by pests *P. rubrofasciatus* and further to estimate soybean yields.

a. Determining the number of damaged pods nymphs due to *P. rubrofasciatus* with mathematical equations as follows:

$$V\frac{\partial \rho_N}{\partial t} - \underbrace{\rho_N A \frac{\partial Z_3}{\partial t}}_{in} + \underbrace{\rho_N A \frac{\partial Z_3}{\partial t}}_{out} = \frac{\text{Number of nymph in CV}}{time} \quad \text{.......................... (9)}$$

b. Determining the number of damaged pods adult due to *P. rubrofasciatus* with mathematical equations as follows

$$V\frac{\partial \rho_I}{\partial t} - \underbrace{\rho_I A \frac{\partial Z_3}{\partial t}}_{in} + \underbrace{\rho_I A \frac{\partial Z_3}{\partial t}}_{out} = \frac{\text{Number of adult in CV}}{time} \quad \text{................................(10)}$$

Model Assumptions. Required several assumptions, including the: (1) Types of soybeans has been determined that Willis, (2) The number of insect populations *P. rubrofasciatus* damaging pods predetermined (accordance with the treatment), (3) The length of time the attack *P. rubrofasciatus* on podshas been set, (4) Models can only be used with input data of the studywith a population (n) which has been determined.

Model testing. to see the reliability models assume the dependent variable in empirical analysis of graphics and statistical analysis between the data model predictions and observations (experiment result) ie by looking liniearity. Validation test was continued by looking at the pattern of spread of residuals by plotting the data with predictions based on the approach of residual method (Graf *et al.*1990). Analysis of statistical data used to determine the validity of a modeland the degree of closeness of relationship between variables by determining the coefficient of determination (R2) and correlation coefficient (r) based on the method of Singh et al. (1996).

RESULTS AND DISCUSSION

The damaged of pods and seed (attacked by*P. rubrofasciatus*).

The average of soybean pods and seed damage attacked by*P. rubrofasciatus as in* thetable 1.

Table 1. Average percentage of pods and seed damage and seed dry weight in the attack of *P.rubrofasciatus*

Treatment	Pod damage (%)	Seed damage (%)	Dry weight (gram)
Po	0.00 a	0.00 a	5.68a
P1	2.14 b	1.07 b	5.10b
P2	3.08 c	1.57 c	4.62bc
P3	3.56 d	3.00 e	3.50d
P4	4.57 e	4.01 f	2.85e
P5	2.31 b	1.65 c	4.51c
P6	3.25 cd	2.15 d	3.86d
P7	4.10 e	4.09 e	2.20f
P8	5.10 f	4.87 g	1.86f

Annotation:
In the same column, the average number followed by the same letter are not significantly different at p: 0.05 at Duncan test

Treatment of both nymphs and adults of infestations showed that nymphs infestation (P1) causing damage to pods as large as adult infestation imago (P5). Nymph infestations (P1) causing damage to the lower seed.Highest seed damage was 4.87%.This damage occurs as a result of adultstreatment (P8).At the time of soybean plants begin pods (R3-4), the presence of 1 tail nymph or adult has to watch out, because the intensity of damage to pods and seeds will further increase when the nymph and adult population continues to grow.This is consistent with the results of Koswanudinresearch(1997) that new pests attacking soybean plants during pod development phase (R3-4).

Nymph infestation influence on pod damage indicates that increasing the number of nymphs were infested, increasing the value of the average percentage pod damage.and to both of them showed a positive correlation (r = 0.99178) with a linear regression equation Y = 1.395 + 0.777 X and the value of R2 = 0.9836. Adult infestation influence on pod damage showed positive correlation (r = 0.9995), the regression equation Y = 1.395 + 0.922 X, and the value of R2 = 0.9991 (Figure 1). Increasing the value of the average percentage pod damage, and to both of them showed a positive correlation (r = 0.9917) with a linear regression equation Y = 1.395 + 0.777 X and the value of R2 = 0.9836.

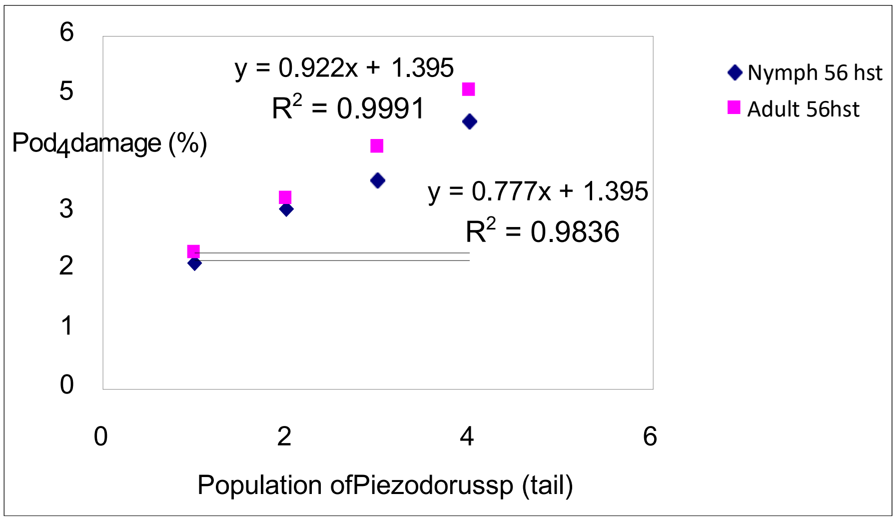

Figure 1. Regression relationship between the population (nymph and adult) with pods damage

Nymph infestation influence on seed damage showed a positive correlation (r = 0.9854) with a linear regression equation Y = - 0.15 + 1.025 X with R2 = 0.9711. Adult infestation influence on seed damage showed a positive relationship (r = 0.97443) with the regression equation Y = 0.29 + 1.16 X, with R2 = 0.9495 (Figure 2)

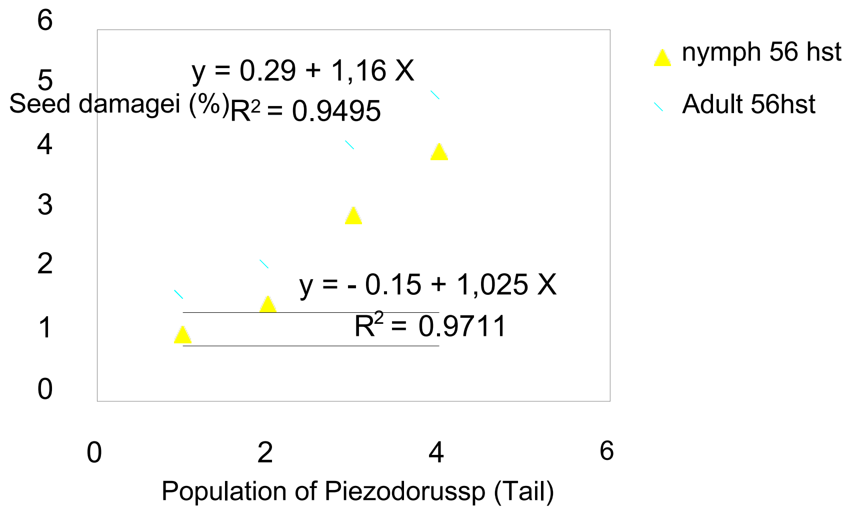

Figure 2. Regression relationship between the population (nymph and adult) with seed damage

Analysis of Pods Damage Estimation Based on Mathematical Model

To estimate the number of soybean pods damaged by the attack of nymphs and adult ofP. rubrofasciatus were used mathematical equations, formula (9) and (10).The results of calculations pods are attacked by nymphs and adults of pod sucking P. rubrofasciatus based prediction models are presented in Table 1. as follows:

Table 1. The average number of soybean pods attacked by a nymph and adult based predictive models.

Perlakuan	Average number of pods attacked (fruits / pods)	Average number of pods attacked (gram)	The average total number of infected pods (gram)
P1	4,62	4,80	10,33
P5	5,32	5,53	
P2	6,58	6,84	14,41
P6	7,28	7,57	
P3	7,56	7,86	16,74
P7	8,54	8,88	
P4	9,52	9,90	20,96
P8	10,64	11,06	

The next step is to calculate the output based on predictive models and experimental results data (empirical) approach with the following formula:

Result = Production Control - number of infected pods (pod sucking nymph and imago) and the data presented in Table 2. as follows:

Table 2. Comparison of yields based models pridiksi and empirical data as well as the magnitude of the error rate (errors)

Treatment	Empirical result (gram)	Model prediction result (gram)	Eror (%)
P_1 and P_5	217,02	217,07	0,023
P_2 and P_6	212,86	212,99	0,061
P_3 and P_7	210,45	210,66	0,099
P_4 and P_8	206,28	206,44	0,077

Comparison of yields between the experimental data with model predictions of data has an error value (error) is very small (0.023 to 0.099%).This shows that the mathematical model is built to predict the soybean crop has a high reliability score (model is very valid). This is in accordance with the opinion of Graft, et al, (1990); Dielemen, et al (1995), and Cousens, et al (1997).Then performed a data plot yields predictions (Y) with empirical results (X) and the results are presented in Figure 3.

Plot data from the model predictions with empirical results in Figure 3.linear regression analysis and further obtained a regression equation Y = 0.9989 X + 0.2146, with p = 0.000 and R2 = 0.9999. Plot the regression line can be seen in Figure 4.

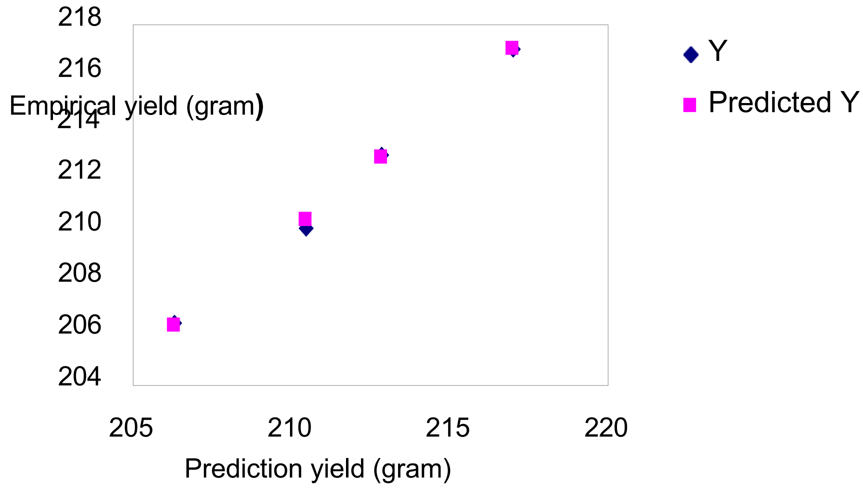

Figure 3. Plot yields (prediction) with empirical results (Y = empirical results; Predected Y = yield prediction)

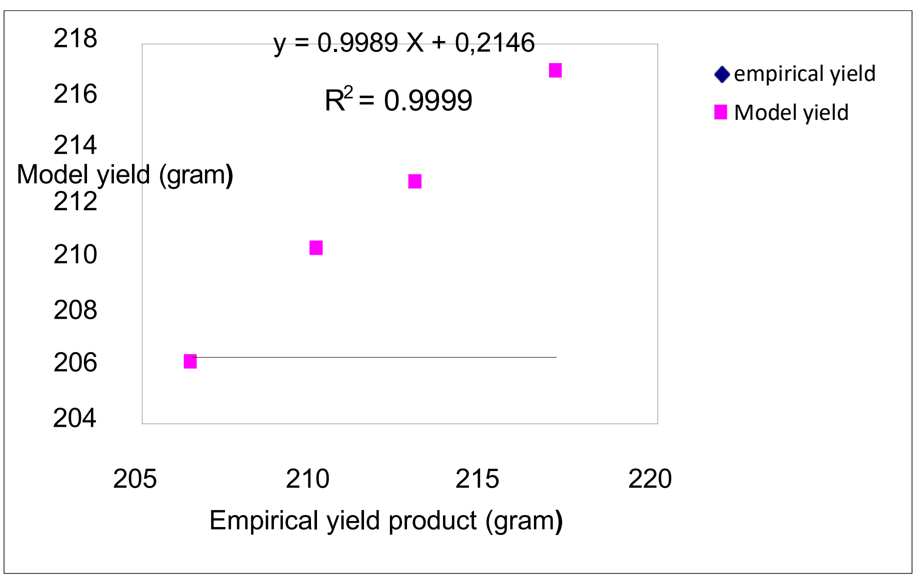

Figure 4. Plot the regression line with the empirical crop yield prediction

CONCLUSION AND SUGGESTION

Conclution

The results showed that :

(1) Relationship between population of *P.rubrofasciatus* and pod damages in the form of mathematical model which is used to predict the soybean pod damage has error 0,02 – 0,10 %.

(2) Mathematical model where made by modification of RTT which is used to predict the soybean yield has error 0,023– 0,099 %.

Suggestion:

To implement this mathematical model in the area of soybean planting, more studies are still needed in. In addition to the assumptions specifically required, also to note some of the requirements of ecological conditions and other external factors in the field (such as other types of pests and natural enemies factor), which will be a limiting factor in the implementation of a mathematical model.

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