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LOGISTIC REGRESSION MODELING OF REDUCTANT HERBICIDE IN PAGARALAM COFFEE FARMING

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ABSTRACT

The presence of weeds can affect the productivity of coffee plants. The use of herbicides that are not wise in controlling weeds can have a negative impact on the quality of coffee production and land. This study aims to obtain a binary logistic regression model of the use of reductant herbicides by coffee farmers in Pagaralam, South Sumatera. This research involved 165 coffee farmers, consisting of 81 farmers who used reductants, and 85 farmers who did not use reductants. In the results of bivariate analysis, variables that have a significant effect on the status of using reductant herbicides do not necessarily have a significant effect on the logistic regression model. The overall prediction accuracy of the model results of the enter method and backward method are respectively 78.2% and 76.4%. The two best models obtained show that farmer age, number of trees, number of family workers, and land productivity can reduce the probability value of farmers using reductant herbicide. On the other hand, variables that can increase the opportunity value of using reductants, starting with the greatest effect, are net income, length of harvest, frequency of herbicide use, frequency of use of organic fertilizers, and age of trees. Based on the factors that affect the use of reductants, coffee farmers should set aside costs for land maintenance, including costs for environmentally friendly weed control, so that they can support the coffee plants to continue producing optimally.

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1. INTRODUCTION

Indonesia is known as an agricultural country, with more than 71% of the population working in the agricultural sector from 2019 to 2021 [1]. Coffee is one of the sub-sectors of the plantation industry and plays an important role in improving the national economy, especially in increasing the prosperity and welfare of the people [2]. Coffee is also one of Indonesia's export commodities, which is quite important as a foreign exchange earner [3]. Almost 96% of coffee plantations in Indonesia are smallholder plantations [4].

Land area is one of the factors that influence coffee production [5] - [9]. South Sumatra (Sumsel) is the largest coffee-producing province in Indonesia which contributed 26% [10]. Coffee production has a very strong correlation with land area. South Sumatra is characterized by the highest area of coffee which includes the area of mature plantations (TM), immature plantations (TBM), and damaged plantations (TR), and also the highest coffee production [11].

In coffee land, not only cultivated plants grow but also weeds. If weeds are allowed to grow in coffee plantations, they can interfere with coffee plants, thereby reducing the productivity of coffee plantations. In general, coffee farmers use herbicides to control weeds. Herbicidal chemicals can also enter the coffee plant tissue so that the coffee beans can be contaminated, which can reduce the quality of coffee and the environment characteristics [12]. Reductant pesticide can reduce pesticide residues on the land and is more economical because it can save on pesticide and land maintenance costs [13]. Therefore, educating farmers about the use of reductants in weed control is very important [14].

Pagaralam is one of 12 coffee-producing regencies/municipalities in South Sumatra. It has 4 superior varieties of robusta coffee [15]. Based on cluster analysis on the 2018 Directorate General of Plantation data, Pagaralam was included in the districts/municipalities that form the same cluster as the other 6 districts and there were no variables that tend to dominate these cluster characteristics [16]. Based on the respondents of Pagaralam coffee farmers in [17], it was found that the average production of 1 tree is closely correlated with land productivity, but production is quite weakly correlated with production costs and income, and very weakly correlated with tree age. Research related to coffee farming in Pagaralam included [18] - [19], who conducted research on factors that affect land productivity and examined the factors that affect farmers' income [20] - [21]. Land productivity was related to coffee production, farmer income, and land maintenance, which included applying fertilizers and using herbicides. These studies did not include the use of reductant herbicide variable.

According to [22], education for farmers in Rimba Candi Village, Pagaralam Municipality, could influence the mindset of farmers in caring for coffee plants, including weed control. They realized the importance of using reductants to minimize the negative effects of using herbicides. The age of the trees and the average planting area per 1 tree were 2 of the 4 factors that distinguish the character of the 2 categories of respondents as users and not users of reductant herbicides [23]. Using the multiple regression model, the qualitative variable in the form of herbicide use did not have a significant effect on the net income of respondents [24]. Education, age of tree, and length of harvest period were some factors that dominantly characterize the dissimilarity in comparison between the categories of non-users and users [25]. If the respondents were divided into 3 categories, namely: users, new users, and non-users, then by correspondence analysis it was found that there were 7 factors related to the status of using the reductant, namely education, tree age, harvest time, frequency of use of herbicides, chemical fertilizers, and organic fertilizers, and also the number of workers from outside the family [26]. In this case, the variables that differentiate farmers' motivation and likelihood to use or not use reductant herbicides have not been studied.

One method for predicting the odds of dichotomous variables is binary logistic regression. Logistic regression is a form of probability model to analyse the relationship between a set of explanatory variables and a qualitative response (categorical) variable that is binary or can also be multinomial [27] - [35]. Some examples of applying the binary logistic regression model are studies of the factors that influence the productivity of songket weavers [36], LBW (Low Birth Weight) status [37], status of the Covid-19 risk zone [38], HDI (Human Development Index) [39], public interest in purchasing flood impact insurance products [40], complex business process [41], land productivity [19] and net income of Pagaralam coffee farmers [20].

Reductant as a reducing agent for the use of herbicides can be an alternative in overcoming the environmental problem. However, not all farmers use reductants in crop cultivation, and coffee farmers in Pagaralam are no exception. Therefore, it is important to examine the changing paradigm of coffee farmers. In this study, a binary logistic regression model is used to determine the factors that influence the use of reductant herbicides on Pagaralam coffee farmers. This study also aims to analyse the factors that can increase or decrease the probability of using reductants so that the characteristics of the farmers' classification can be seen. In this logistic regression modelling, the results of the enter and stepwise methods are compared to obtain for the possible status of reductant use. The results of this study are expected to be used as reference material regarding Pagaralam coffee farming, especially the social and cultural characteristics of coffee farmers in land care. Factors that can increase and decrease farmers' probabilities to use reductants can be input for related parties in efforts to cultivate sustainable agriculture.

2. RESEARCH METHODS

The research population was coffee farmers in South Dempo District and Dempo Tengah District, Pagaralam Municipality. Coffee farmers were taken as samples by purposive sampling. The number of samples used in this research was 165 respondents (from coffee farmers), consisting of 81 farmers who used reductants and 84 farmers who did not use reductants. The variables used were the use of reductant (Y) as a dependent variable and 15 independent variables. The measurement scale of all independent variables is ordinal. The category of the dependent variable is denoted as 0 for a respondent who does not use reductant and 1 for a respondent who uses it.

The notations of 15 independent variables used are X_1 as Education, X_2 as Age of farmer, X_3 as Length of farming experience, X_4 as Number of trees, X_5 as Age of tree, X_6 as Frequency of herbicide use, X_7 as Frequency of chemical fertilizer use, X_8 as Frequency of organic fertilizer use, X_9 as Number of workers in the family (or TD), X_{10} as Number of workers outside family (or TL), X_{11} as Land maintenance costs, X_{12} as Net income, X_{13} as Coffee bean production, X_{14} as Length of harvest period, X_{15} as a Land productivity. These variables consist of 3 to 5 categories. The organic fertilizer defined in X_8 is organic matter in the form of coffee berry husks added with animal manure that has not gone through a further composting stage.

If X and Y are two variables that respectively have a and b categories, then an observation data matrix $\boldsymbol{P} = (n_{ij})$ can be formed with size $a \times b$ with $n_{ij} \geq 0$ representing the frequency of cells (i, j). In this research, "a" states the number of categories of an independent variable. Whereas "b" states the number of categories of dependent variable, that is 2 categories. The stages of analysis in binary logistic regression model are as follows:

1. Conduct a bivariate analysis to analyse the relationship between the use of reductant variables (as column category variables) and other variables (as row category variables) with the following analysis stages:

a. Arranging a contingency table. One of the requirements of the contingency table is that the number of cells n_{ij} with an expected frequency of less than 5 cannot exceed 20% of the total of cells. If it is more than 20% then cell merging is carried out [42].

b. Perform an independence test using the chi-square (χ^2) test statistic.

The hypothesis used is:

H_0 : There is no difference in the proportion of status not using reductants and using reductant herbicides based on the row variables.

H_1 : There is a difference in the proportion of status using reductants and not using reductant herbicides based on the row variables.

Chi-square test statistics is

$$\chi^2 = \sum_{j=1}^{b} \sum_{i=1}^{a} \frac{(o_{ij} - e_{ij})^2}{e_{ij}} \quad (1)$$

where the expected frequency value:

$$e_{ij} = \frac{(total\ row)(total\ column)}{total\ observations} = \frac{(n_{i.})(n_{.j})}{n_{..}} \quad (2)$$

o_{ij} : the observation value of the i-th row and j-th column

$\boldsymbol{e_{ij}}$: the expected value of the $\boldsymbol{i}$-th row and $\boldsymbol{j}$-th column j; $\boldsymbol{i = 1, 2, \dots, a}$; $j = 1, 2, \dots, b$.

The value of $\boldsymbol{\chi^2_{tabel}}$ is chosen by a significance level of $\boldsymbol{\alpha}$ = 0.05 and with degrees of freedom *df* = (*a* – 1) (*b* – 1). The test criteria, that is, if $\chi^2_{count} \geq \chi^2_{\text{table}}$ or if Sig. < 0.05 then reject H_0. Otherwise, accept H_0.

c. Calculating the *Odds ratio* (OR) in the contingency table of variables related to the status of the use of reductant herbicides. OR is a comparison measure used to calculate the probability that the value is X = 1 or X = 0. The odds value for X is $\frac{\pi(x)}{1-\pi(x)}$. The natural logarithms of the odds X = 1 and X = 0 are $g(1) = \ln\frac{\pi(1)}{1-\pi(1)}$ dan $g(0) = \ln\frac{\pi(0)}{1-\pi(0)}$, where $g(x) = \ln\frac{\pi(x)}{1-\pi(x)}$ [43].

2. Estimate the parameters of the probability function $\pi(x)$ [26]:

$$\pi(x) = \frac{\exp(\beta_0+\beta_1+\cdots+\beta_{15}x_{15})}{1+\exp(\beta_0+\beta_1+\cdots+\beta_{15}x_{15})} \tag{3}$$

There are two ways to estimate the logistic regression model, namely the overall method (or known as the enter method) and gradually (or known as the stepwise method). The enter method is carried out by entering all the independent variables, then evaluating which independent variables have a significant effect on the dependent variable. Meanwhile, the stepwise method is carried out by selecting automatically only the independent variables that affect the dependent variable [23]. The stepwise method is a method in regression analysis that helps the analysis process to get the best model [44].

3. Evaluate the logistic regression results:

by the Goodness of Fit test, the significance test of the effect of all independent variables simultaneously (overall model fit) and partially (significance test) on the dependent variable.

a. Conduct a model feasibility test (Goodness of Fit) with a coefficient of determination (R^2).

The R^2 value is a poor measure in logistic regression, so it is called a *Pseudo* R^2. There are two *Pseudo* R^2 measures, namely *Cox and Snell* and *Negelkerke*. The feasibility test of the model used the Hosmer and Lemeshow test which is based on the chi-square test statistic.

b. Do a simultaneous test to determine the effect of all the independent variables contained in the model simultaneously on the dependent variable. The hypothesis tested is as follows:

$H_0: \beta_k = 0; \forall k = 1,2,\ldots,15$ (no significant effect between the independent variable and the dependent variable)

$H_1: \exists \beta_k \neq 0; \forall k = 1,2,\ldots,15$ (there is a significant effect between the independent variable and the dependent variable)

Test statistics used is

$$G = -2\ln(L_0 - L_k) \tag{4}$$

L_0 is Likelihood without independent variables and L_k is likelihood with independent variables.

Criterion H_0 is rejected if the value $G > \chi^2_{(n-p,\alpha)}$ where n is the number of observations and p is the number of independent variables [45]. In this research, n = 165 and p =15.

c. Do a partial test using the omnibus test which is based on the chi-square test statistic.

Partial testing is used to determine the significance of the independent variable X_k partially to the dependent variable by assuming that the other independent variables are considered constant. Parameter partially testing (for $k = 1, 2, \cdots, 15$) was carried out by the Wald test. The hypothesis tested is as follows:

$H_0: \beta_k = 0$ (no effect between the *i*-independent variable and the dependent variable)

$H_1: \beta_k \neq 0$ (there is effect between the *i*-independent variable and the dependent variable).

Test statistics used is

$$W_k = \frac{\hat{\beta}_k}{\widehat{SE}(\hat{\beta}_k)} \tag{5}$$

where $\hat{\beta}_1$ is regression coefficient estimator and $\widehat{SE}(\hat{\beta}_1)$ is standard error of the estimator of $\hat{\beta}_1$.

Test criteria: H_0 is rejected if the value $W > Z_{\alpha/2}$ or *p-value* $< \alpha$.

4. Choose the best model by comparing the enter and stepwise methods.
5. Interpret the model and the results obtained.
6. Make conclusions from research results.

The calculation process at each stage of the analysis is carried out using SPSS 26 and Minitab 19 software tools.

3. RESULTS AND DISCUSSION

The notations of 15 independent variables used are $X_1, X_2, \ldots, X_{15}$. These variables consist of 3 to 5 categories, so "*a*" can be equal 3, 4, or 5. The dependent variable *Y* is divided 2 categories.

3.1. Bivariate Analysis

Bivariate analysis was conducted to see the relationship between the two variables. A test of this relationship used the independence test by the chi-square test statistic. An example for the relationship between education and the use of reductant herbicide. There were 2 respondents who did not complete SD in the category of education and the number of cells whose expected frequency was ≤ 5 was more than 20%. Because the education variable was on an ordinal scale, the not completed in SD category was combined with the SD category. The contingency table can be shown in **Table 1**.

Table 1. Contingency Table for Education Categories After Merging Cells

Education	Use of reductants		Total	χ^2	*Odds Ratio (OR)*	*1/OR*
	Not using	Using				
SD	22	30	52			
SMP	11	19	30	8.43	1.27	0.79
SMA	41	23	64		0.41	2.43
Bachelor	10	9	19		0.66	1.52
Total	84	81	165			

Based on **Equation (1)**, we get χ^2_{count} of 8.43 and for α = 0.05 with degree of freedom *v* = 3. Because of χ^2_{table} =7.81, so $\chi^2_{count} > \chi^2_{table}$. The results of this chi-square test produce a rejection of H_0 and it can be concluded that there is a relationship between education and the use of reductants. In the same way, a recapitulation of the results is obtained as shown in **Table 2**. The merging of categories on the contingency table occurs in Frequency of herbicide use, TL, and Frequency of use of chemical fertilizers variables.

Table 2. Recapitulation of Independence Test Results between Row Variables and Reductant Use Variable

Row Variable	χ^2_{count}	$p-value$	Test result	Explanation
Education	8.43	0.038	Reject H_0	**Statistically significant**
Age of farmer	2.89	0.409	Accept H_0	There is no relation
Length of farming experience	2.35	0.502	Accept H_0	There is no relation
Number of trees	5.73	0.126	Accept H_0	There is no relation
Age of tree	23.29	0.000	Reject H_0	**Statistically significant**
Frequency of herbicide use	9.31 *8.084	0.025 *0.018	Reject H_0	**Statistically significant**
Frequency of chemical fertilizer use	7.11 *3.34	0.068 *0.188	Accept H_0	** There is no relation
Frequency of organic fertilizer use	10.82	0.004	Reject H_0	**Statistically significant**
TD	13.19	0.004	Reject H_0	**Statistically significant**
Number of workers outside the family (TL)	23.53 *5.29	0.000 *0.071	Reject H_0	**Statistically significant**
Land maintenance costs	3.60	0.462	Accept H_0	There is no relation
Net income	5.62	0.132	Accept H_0	There is no relation
Coffee bean production	3.41	0.332	Accept H_0	There is no relation
Length of harvest period	20.29	0.000	Reject H_0	**Statistically significant**
Land productivity	5.40	0.145	Accept H_0	There is no relation

Note: *The value of* $\chi^2_{table(\alpha=0.05)}$ *for degree of freedom df = 3, df = 4, and df = 5 respectively is 7.81, 3.84, and 5.99. The * notation states that the* χ^2 *test results are for variables that occur in merging categories. The ** notation states that the test results use a significance level of* α *= 10%. The results of the independence test can also be seen in (Irmeilyana, et al., 2022c).*

In **Table 2**, the variables that have a significant effect on the status of using reductant herbicide are Education, Age of tree, Frequency of organic fertilizer use, Frequency of chemical fertilizer use, TL, TD, and Length of harvest period. But if there is a merging of categories in TL variable, then this variable has a significant relationship to the use of reductants at α = 5%. It can be interpreted that these variables influence the mindset of farmers in deciding whether to use reductant herbicide or not. For old trees, if they are not cared for properly, especially through proper fertilization and wise weed control, then they will affect the quality and quantity of coffee fruit production. Farmers who fertilize mainly with organic fertilizers have a tendency to also pay attention to weed control efforts in a more environmentally friendly manner.

Furthermore, to interpret the comparison of event possibilities between categories on the status of using reductant herbicide, the odds ratio value is used. For example, in the categories of education in **Table 1**, the tendency of farmers with elementary school education and not graduating from elementary school not to use reductant is 1.27 times that of farmers with junior high school education. While the tendency of farmers with elementary education not to use reductants is 0.41 times compared to farmers with high school education. In this case, the tendency for farmers with elementary education to use reductants is 2.43 times that of farmers with high school education. In the same way, the tendency for the use of reductant in farmers with elementary education is 1.52 times compared to farmers with a bachelor's education.

The recapitulation of the OR values on the variables related to the status of the use of reductant can be seen in **Figure 1**. The high odds ratios in the categories of age of tree, frequency of herbicide use, frequency of organic fertilizer use, and length of harvest period, indicate that the higher the category in these variables. So, those have impact on the tendency of farmers to use reductant are also higher compared to the comparison category (on first category).

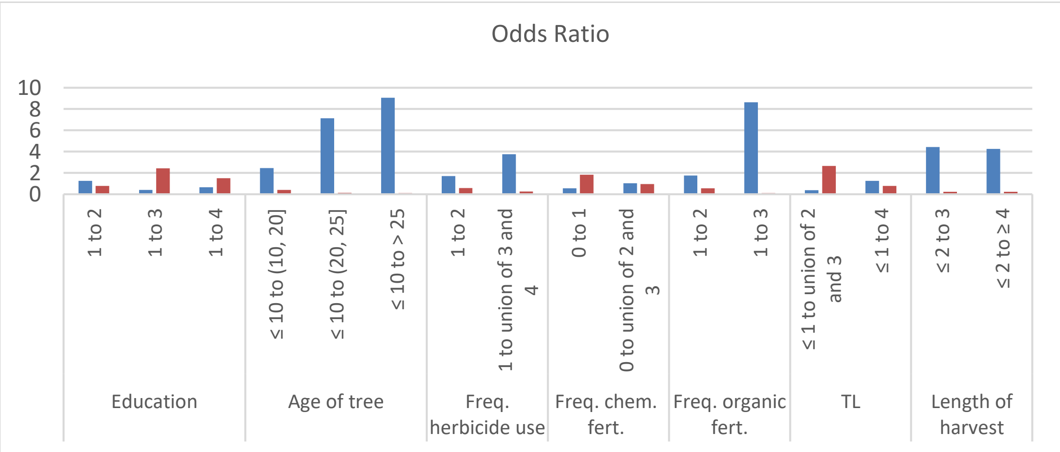

Figure 1. The OR Values of Every Categories of Significant Independent Variables

3.2. Multivariate Analysis

Probability modeling of the use of reductant on Pagaralam coffee farmers was carried out using binary logistic regression. Estimation of the best logistic regression model is done by using the enter, forward stepwise, and backward stepwise methods. The independent variable data used in the modeling includes the initial data and the data after merging the categories (hereinafter referred to as the merged data).

Some of the outputs of the logistic regression model by SPSS software are presented in **Table 3** and **Table 4**. The Omnibus test provides a simultaneous test of all variable coefficients in logistic regression. The classification table provides information about the accuracy of predictions, namely how well the model classifies cases into two groups, namely, use reductant and do not use reductant. The goodness of fit test is presented in Cox & Snell R^2 and Nagelkerke R^2, which states the percentage ability of the logit model to explain the categorization of farmers in using or not using reductant herbicide. Hosmer and Lemeshow test to measure whether the predicted probabilities match the observed probabilities. The test uses the chi-square test. If the chi-squares test is not significant, then the predicted probabilities correspond to the observed probabilities.

The significance test of the independent variables individually (partially) uses the Wald statistical test in **Equation (5)**. **Table 3** presents the tests on the results of the three methods in the last iteration. Based on the criteria for the best model, the value of the accuracy of the predictions, and the goodness of fit in **Table 3**, the best model chosen is the model resulting from the enter method on the merged data. The model of the two data produces 8 significant variables at α = 5%, but the value of R^2 and the accuracy of the model on the merged data are greater than the initial data.

Table 3. Test Results on The Output of The Enter, Forward Stepwise, and Backward Stepwise Methods

Item	Enter method		Forward method		Backward method	
	Initial data	Merged data	Initial data	Merged data	Initial data	Merged data
Number of iterations	1	1	6	5	7	7
Sig. value on the Omnibus test	0.00	0.00	0.00	0.00	0.00	0.00
Goodness of fit						
Cox & Snell R^2 (in %)	35.6	36.7	26.9	26.0	32.9	33.1
Nagelkerke R^2 (in %)	47.5	49	35.8	34.7	43.8	44.2
Sig. value on the Hosmer & Lemeshow test	0.874	0.898	0.431	0.728	0.415	0.705
Classification table (predictive accuracy)						
Non users “0” (in %)	76.2	77.4	72.6	73.8	76.2	76.2
Users “1” (in %)	79.0	79.0	74.1	66.7	76.5	76.5
Overall percentage	77.6	78.2	73.3	70.3	76.4	76.4
The number of significant independent variables	8	8	6	5	9	9
Age of farmer	X_2	X_2			X_2	X_2
Number of trees	$*X_4$	$*X_4$			X_4	X_4
Age of tree	X_5	X_5	X_5	X_5	X_5	X_5
Frequency of herbicide use	X_6	X_6	X_6	X_6	X_6	X_6
Frequency of organic fertilizer use	X_8	X_8	X_8	X_8	X_8	X_8
Number of workers in the family (TD)	X_9	X_9	X_9		X_9	X_9
Net income	X_{12}	X_{12}			X_{12}	X_{12}
Length of harvest period	X_{14}	X_{14}	X_{14}	X_{14}	X_{14}	X_{14}
Land productivity	X_{15}	X_{15}	X_{15}	X_{15}	X_{15}	X_{15}

Description: **) indicates that at the significance level α = 10%, the sig. value of variable < 0.100.*

The positive or negative sign of the variable coefficients on all model outputs are the same. In the backward method output, there are 9 independent variables that have a significant effect on α = 5%, which includes 8 variables on the enter method output and added the number of trees variable. If it is related to the cases studied, in quantitative data, the number of trees is very closely correlated with land area (i.e., with value of 0.91), so that the larger the land area, the higher the number of trees. This has an impact on the higher volume of herbicide used for weed control, so that it can increase the probability of farmers to use reductant herbicides. But if the modeling is done using the enter method, the number of trees is also a variable that has a significant effect on the status of the use of reductant herbicides. In this case, the models chosen to represent the factors that have a significant effect on the use of reductant herbicides are the output model of enter and the backward stepwise methods on the merged data. Some of the factors that have a significant effect are not variables related to the status of the use of reductants from the bivariate analysis results. The variables are age of farmer, number of trees, net income, and land productivity.

Based on **Table 3**, the results of the Omnibust test on the model yield sig. 0.000, which means rejecting H_0 so that all independent variables simultaneously affect a farmer's decision to use reductant herbicides. The Cox & Snell R^2 value indicates that the variability of the independent variables in the model can explain the categorization of farmers who use or do not use reductant herbicides by 36.7%. There are 100% -36.7% = 63.3% which are other factors outside the model that explain the dependent variable. Likewise, Nagelkerke R^2 shows the ability of the model to explain the categorization of farmers who use or not use reductant herbicides is by 49%.

The Hosmer and Lemeshow test results show that the chi-squares test is not significant (i.e. 0.898), so that the predicted probabilities correspond to the observed probabilities. The results of the classification table show how well the model classifies the use of reductants into 2 categories. The overall prediction accuracy obtained is 78.2%. Meanwhile, the prediction accuracy for not using reductant herbicides was 77.4% and using reductants was 79.0%.

The logistic regression in **Equation (3)** can be interpreted by the Exp (β_k) value, which is also the Odds Ratio (or abbreviated as OR). The variables of the significance test result, along with the logit (β_k) and regression coefficient values Exp (β_k) for the output of enter and the backward stepwise methods on the merged data can be seen in **Table 4**.

Table 4. The Value of Logit Regression Coefficient on The Output of Enter and Backward Stepwise Methods

Significant variables (X_k)	**Enter Method**		**Backward Stepwise Method**	
	β_k	**Exp** (β_k)	β_k	**Exp** (β_k)
Age of farmer (X_2)	-0.845	0.429	-0.490	0.613
Number of trees (X_4)	-0.460*	0.631	-0.525	0.591
Age of tree (X_5)	0.610	1.841	0.711	2.036
Freq. of herbicide use (X_6)	1.022	2.778	0.786	2.194
Freq. of organic fertilizer use (X_8)	0.880	2.412	0.901	2.462
TD (X_9)	-0.914	0.401	-0.774	0.461
Net income (X_{12})	1.387	4.003	0.878	2.405
Length of harvest period (X_{14})	1.213	3.364	0.919	2.506
Land productivity (X_{15})	-0.871	0.418	-0.977	0.376
Constants**	-0.918	0.399	-0.857	0.425

Description: *) *indicates that at the significance level α = 10%, a sig. value of Number of trees variable is 0.10. **) Constants with its sig. value is more than 0.10, that is, on the results of the enter method is 0.565, and the results of the backward method on step 7 is 0.507.*

Based on **Table 4**, the selected model is the result of modeling by the enter method (but at α = 10%), namely:

$$\pi(x) = \frac{\exp(-0.918-0.845X_2-0.460X_4+\cdots-0.871X_{15})}{1+\exp(-0.918-0.845X_2-0.460X_4+\cdots-0.871X_{15})} \tag{6}$$

and also, by backward stepwise method, namely:

$$\pi(x) = \frac{\exp(-0.857-0.490X_2-0.4525X_4+\cdots-0.977X_{15})}{1+\exp(-0.857-0.490X_2-0.4525X_4+\cdots-0.977X_{15})} \tag{7}$$

When viewed from the β_k value, each variable in both models produces the same positive and negative signs. The negative coefficients are on the age of farmer, the number of trees, the number of the workers from within the family, and the land productivity variables. Variables with negative coefficients can reduce the probability value $(\pi(x))$ of the model. Conversely, the positive coefficients of variables can increase the probability value $(\pi(x))$ of the model. Variables with positive coefficients are age of tree, frequency of herbicide use, frequency of organic fertilizer use, net income, and length of harvest period.

OR shows the magnitude of the influence of each category of the independent variables on the probability of the use of reductant. Based on the OR of the model in **Equation (6)**, the Net income variable has the greatest influence in determining the use of reductants by coffee farmers, which is equal to 4.003. This can be interpreted that each increase on category of Net income can lead to an increase in the use of reductants by coffee farmers which is 4.003 times greater. The length of harvest period variable has the second largest effect after net income, namely with an odds ratio of 3.364. It can be said that every one-month increase on the harvest period (according to the category of variable) will cause an increase in the use of reductants by coffee farmers which is 3.364 times greater.

Furthermore, the Frequency of herbicide used and Frequency of organic fertilizer used variables, respectively have an odds ratio of 2.778 and 2.412. So, for each increase in the category of the two variables, it will respectively cause increase in the use of reductant by coffee farmers, which is 2.778 and 2.412 times greater. The age of tree variable can also cause an increase in the use of reductants by coffee farmers, which is 1.841 times greater.

The probability for farmers to use reductant will be higher if the categories of the age of tree and the frequency of organic fertilizer use are higher, but those are accompanied by a decrease on the category of land productivity. Conversely, an odds ratio that is less than 1, namely the number of trees, age of the farmer, land productivity, and the number of TD can be affected on the probability of the use of reductant by coffee farmers decrease. This can be interpreted that whenever there is an increase in the category of these variables, it can result in the possibility of a decrease in the use of reductants by farmers. If the category values of these variables are high, then the probability of the use of reductant herbicide by farmers will be low.

Furthermore, the best logistic regression model obtained in **Equation (6)** can be used to calculate the probability of farmers using reductant herbicide through a simulation in combination of all category values of significant independent variables. The number of possible combinations is 110,592. So, **Table 5** only presents 15 combinations that consist of 5 combinations for each category of frequency of herbicide used, namely in the category where the respondents are the most, in the lowest category of each variable, in the highest category of each variable, the combination of variables that have a positive coefficient sign on the highest category and the negative coefficient sign on the lowest category, and apposite of the last combination.

Based on the value of $\pi(x)$ for each combination of variable values that are especially for cases A to C in **Figure 2**, the higher the frequency of herbicide use, the higher the probability for farmers to use reductant. The probability of farmers using reductants in case C (the category of each variable is the highest category) is higher than in case B (the category of each variable is the lowest category) and also in case A (i.e., the category where the number of respondents is the highest).

The probability of using reductants by farmers at each frequency of herbicide use in case A is the lowest compared to the probability values in Cases B and C. By a frequency of herbicide use is 3-4 times a year (category 3), the farmers that their age are 40-50 years, have a number of trees ≤ 2,500 stems, their trees age are 10-20 years, do not use organic fertilizers, are usually assisted by 2 family members, have Net income of 9 till to 18 million rupiahs, have harvest period along 3 months, and have land productivity of 500 - 1,000 kg/ha, then they tend to have probability to use reductant of 0.881. However, if the farmers use the herbicide 1 time and 2 times a year, then the probability of using the reductant herbicide will be 0.49 and 0.727, respectively.

Table 5. The Value of $\pi(x)$ in Several Combinations of Variable Values for Each Category of X_6

Combination	Category of variable									$\pi(x)$
	X_2	X_4	X_5	X_6	X_8	X_{10}	X_{12}	X_{14}	X_{15}	
A	3	1	2	1	0	1	2	2	2	0.490
B	1	1	1	1	0	1	1	1	1	0.556
C	4	4	4	1	2	4	4	3	4	0.756
D	1	1	4	1	2	1	4	3	1	1.000
E	4	4	1	1	0	4	1	1	4	0.000
A	3	1	2	2	0	1	2	2	2	0.727
B	1	1	1	2	0	1	1	1	1	0.777
C	4	4	4	2	2	4	4	3	4	0.896
D	1	1	4	2	2	1	4	3	1	1.000
E	4	4	1	2	0	4	1	1	4	0.000
A	3	1	2	3	0	1	2	2	2	0.881
B	1	1	1	3	0	1	1	1	1	0.906
C	4	4	4	3	2	4	4	3	4	0.960
D	1	1	4	3	2	1	4	3	1	1.000
E	4	4	1	3	0	4	1	1	4	0.001

Description: *The combination of A consists of categories that have the most respondents; B consists of the lowest category in each variable; C consists of the highest category in each variable; D consists of the highest category on each variable that has a positive coefficient and the lowest category on each variable that has a negative coefficient; E consists of highest category on each variable that has a negative coefficient and lowest category that has a positive coefficient.* X_2*: Age of farmer;* X_4*: Freq. of organic fertilizer use;* X_{10}*: TD;* X_{12}*: Net income;* X_{14}*: Length of harvest period;* X_{15}*: Land productivity.*

Case C can be interpreted that farmers that have aged > 50 years have number of trees > 5,500 stems, tree age > 25 years, frequency of using organic fertilizer ≥ 2 times a year, and involve family workers (TD) ≥ 4 people, have net income > 27 million rupiahs, the harvest time > 4 months, the land productivity > 1,500 kg/ha, and the frequency of using herbicides is 3 - 4 times a year, then the farmers have probability to use reductants of 0.96 or 96%. Meanwhile, if the frequency of herbicide use is 1 time and 2 times, then the probability will be 0.756 and 0.896, respectively. This represents that if the farmer's age, the number of trees, the age of the trees, the net income, the productivity of the land, the frequency of organic fertilizer use, and the number of TD are higher, then on the frequency of using herbicides 2 to 4 times a year, probability to use reductants will be higher.

Conversely, in case B, when all variable categories are lowest, namely the farmers that have aged ≤ 30 years, have number of trees ≤ 2,500, have tree age ≤ 10 years, never used organic fertilizer in a year, involve labor from within the family (TD) ≤ 1 person, have Net income ≤ 9 million rupiahs, harvest time ≤ 2 months, and Land productivity ≤ 500 kg/ha, then by the frequency of using herbicides 1 time a year, the probability of farmers using reductants is low, namely 0.556 or 55.6%. This represents that the lower the farmer's age, the number of trees, the age of the tree, the net income, the lower land productivity due to the absence of the use of organic fertilizer, and involves only 1 TD or not, then, by the frequency of using herbicides once a year, it can lead to probability of reductant use is low. In this combination of variable values, if the farmer uses herbicides 2 times and 3 - 4 times a year, then the probability of using reductant herbicides will be 0.777 and 0.906, respectively.

Whereas in case D, because the variable with a negative coefficient has the lowest category value and the variable with a positive coefficient has the highest category, the probability of farmers to use a reductant is close to or equal to 1. In contrast, for case E, the probability of farmers of using reductants is close to or equal to 0. In this case, it can be interpreted that if the coffee farmers that have age ≤ 30 years, number of trees ≤ 2,500, tree age > 25 years, use organic fertilizer ≥ 2 times a year, involving labor from within the family (TD) ≤ 1 person, net income > 27 million rupiahs, harvest period for > 4 months, land productivity ≤ 500 kg/ha, then at each frequency of herbicide use, the probability of farmers to use reductant will be very high, even equal to 1. In this case, almost 100% of farmers will use reductant herbicides.

Conversely, if the coffee farmers aged > 50 years, number of trees > 5,500 stems, tree age ≤ 10 years, never used organic fertilizer in a year, involving family labor (TD) ≥ 4 people, net income ≤ 9 million rupiahs, harvest period ≤ 2 months, land productivity > 1,500 kg/ha, then at each frequency of herbicide use, the probability to use reductants will be very low, even close to and equal to 0. In this case, almost all farmers tend not to use reductants.

The calculation of the value of $\pi(x)$ is carried out for all possible category combinations of the 9 significant variables. The results of calculating the probability value $\pi(x)$ of the use of reductant herbicides for each combination of these categories can be represented in Figure 2.

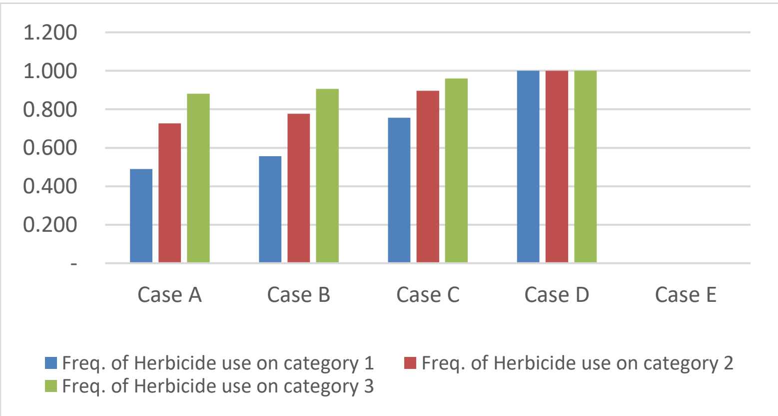

Figure 2. Representation of $\pi(x)$ on Several Examples of Categories Combination of Variable Values

If the modeling results are related to the real situation in the field, it can be interpreted that younger farmers have a greater chance of accepting innovation, including in weed control, that is more environmentally friendly. Farmers use organic fertilizers (composted coffee husk) because fertilizer prices are expensive, so they can save land maintenance costs. Farmers also save on herbicide use by adding reductants so that it is more economical.

The number of trees is closely correlated with land area. The more trees, the smaller the planting area per tree, so the weed density is also less. This can reduce the frequency of herbicide use. Farmers who use herbicides have a great opportunity to use reductants on the basis of cost savings and also awareness of the importance of reducing herbicide residues on land. Farmers whose net income is higher have a higher probability to use reductants because farmers have more capital to take care of their farming, including weed control.

The longer harvest period is accompanied by a higher amount of production, which can affect income and costs that can be set aside for caring for farming, including weed control. The old trees should be accompanied by better care so that they can continue to produce high. Low land productivity can encourage farmers to take care of their crops more intensively, including land care.

4. CONCLUSIONS

In the results of bivariate analysis, variables that are significantly related to the status of the use of reductant herbicide do not necessarily have a significant effect on the logistic regression model. In the model, there are 9 factors that have a significant influence on the classification of farmers' status in using reductants. Farmer age, number of trees, number of workers within a family, and land productivity can reduce the probability value of farmers using reductant herbicide. On the other hand, variables that can increase the probability value of using reductants, starting with the greatest effect, are net income, length of harvest time, frequency of herbicide use, frequency of organic fertilizer use, and age of trees. Several examples of combinations of variable values show that the frequency of herbicide use greatly influences the relatively large increase in the probability value of reductant herbicide use.

Because the length of the harvest period affects the possibility of increasing the use of reductants, it is necessary to investigate further the influence of the culture of land maintenance on the harvest period and the maturity period for cherries to be ready for harvest. Based on the factors that affect the use of reductants, coffee farmers should set aside their income for land maintenance, including costs for environmentally friendly weed control and the use of organic fertilizer, so that they can support coffee plants to continue producing optimally. Old coffee trees and land affected by residues from herbicides tend to have low land productivity. Therefore, in order to increase and maintain land productivity, it is suggested to farmers to use organic fertilizer and reductant herbicide in coffee farming. Old coffee trees and land affected by residues from herbicides tend to have low land productivity. Therefore, one way to maintain land productivity is if farmers use herbicides, then they should mix them with reductants.

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