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ESTIMATION OF CATTLE WEIGHT GAIN UNDER THE INFLUENCE OF METEOROLOGICAL AND NUTRITIONAL VARIABLES BY APPLYING A MULTIPLE LINEAR REGRESSION MODEL IN SABANALARGA, COLOMBIA

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ABSTRACT

The present investigation arose from the current problem in the entire territory of the Department of Atlántico in the Republic of Colombia, in which the livestock sector currently lacks a reliable modernization that contributes to the planning and profitability of meat production, translated into weight gain. The main focus of the study gravitated around the ignorance of the real effect exerted by meteorological and nutritional factors on the weight gain of cattle. As a possible solution, it was proposed to carry out a statistical analysis by means of a multiple linear regression model where cattle weight gain was the dependent variable to study under the influence of the following independent variables: accumulated precipitation for two weeks (mm), average daily precipitation for two weeks (mm), average daily forage height consumed for two weeks (cm), percentage daily average of forage consumed during two weeks (%), average protein percentage of forage consumed during two weeks (%), the average maximum temperature recorded during two weeks (°C), the average minimum temperature recorded during two weeks (°C), average daily temperature variation recorded for two weeks (°C) and average relative humidity recorded for two weeks (%). All independent data values were collected in the field. Once the analysis was carried out, it was concluded that there was statistical evidence to affirm that only the independent variables "accumulated precipitation", "average precipitation", "average minimum temperature" and "relative humidity" significantly influenced the changes observed in profit of cattle weight, being formulated a multiple linear regression model that contained only the mentioned variables, the rest were discarded. On the other hand, for the constructed linear regression model, the coefficient of determination R2 = 89.3691% was obtained, that is, for the significance level α = 0.05 (95% confidence level), this determined that the model of Multiple linear regression (A) explained the behavior of the average monthly cattle weight gain by 89.3691%. It was concluded, therefore, that the present work gives veracity to the determination of previous investigations where it is also concluded that the meteorological variables directly affect the changes associated with the weight of cattle for meat production.

Key words: cattle, linear regression, livestock, meteorological, nutritional, statistics, variables, weight gain

INTRODUCTION

According to figures provided by the Agustín Codazzi Geographic Institute (IGAC), the Department of Atlántico allocates approximately 144,000 hectares for the development of livestock activity. In other words, close to 43.5% of the territory is exploited by this sector. Likewise, it should be noted that the vast majority of those who carry out this economic activity are small and medium-sized producers who carry out traditional work practices, which translates into little technification in developing agro-productive processes [1]. In this context, the lack of strategies associated with the planning of forage crops, the high costs associated with disease care, as well as the scarce technical assistance, and the deficient implementation of new technologies in the development phases of the system production, unleash effects that translate into low competitiveness within the agro-industrial sector and more robust barriers to establishment within markets that demand quality standards related to the reduction of agrochemical products, higher rates of modernization of the productive system and sustainable management [2].

For livestock, the lack of investment in new technology has multiple consequences, and among the most serious is the high cost of monitoring and managing livestock [3]. Since livestock farming requires large areas, it is not possible to establish a fixed security system to track livestock [4], and administrators have to delegate functions to third parties. This creates inconsistencies in inventory reporting and the control of the resource itself [5]. In this order of ideas, in the Department of Atlántico there are currently no systems or programs that support producers in the region [6]. For example, there are no comparative tables of the region's native pastures, which represent valuable data for decision-making in livestock, such as a height table for input and output pastures, which generates better animal nutritional performance, as well as productivity and optimization of use for the self-generation of livestock feed [7]. Among all the deficiencies already mentioned, there is also no supply of statistically accurate information for the development of an in-depth analysis on which the elements that have the greatest incidence on weight gain of cattle, which is, in turn, the variable around to which all the methods applied and in development gravitate within the context of livestock exploitation [8]. Said analyzes would allow conclusions that substantially and positively affect decision-making, in addition to supporting a cutting-edge agro-industrial management that is presented in accordance with the needs and demands of the global and updated context faced by said economic sector [9].

For practical purposes, it is difficult to find, to date, a small or medium-sized livestock producer who knows for sure the effect that external variables can have on weight changes in cattle [10]. Otherwise, extremely useful information would be displayed for the operational and financial planning of the entire livestock sector. Various authors agree that weight gain significantly influences the profitability of bovines, but in turn, it explains how limited are currently the studies that include cattle kept under certain weather conditions, either with respect to precipitation, environmental humidity, or temperature [11].

It is for all of the above explained that in the present study, a set of observations of different meteorological and nutritional variables is collected to measure their effect on a set of data collected relative to the weight increase of cattle from a sample of forty adult specimens subjected to the same conditions in the Sabanalarga municipality of the Department of Atlántico, in the Republic of Colombia. In such a way that the weight gain of cattle was taken as a dependent variable and the effect exerted on it by climatic and nutritional factors will be measured in the form of independent variables, by means of a multiple linear regression model [12]. Being one of the simplest and most moldable statistical models to each particular set of data, the objective of its application in this research is to verify its feasibility within the agricultural context to measure and predict the weight gain of cattle under the influence of climate and the proposed nutritional variables [13].

The main purpose of this article is the optimization and efficient use of resources for livestock feeding, processes that in the livestock sector of the region studied in this study are deficient, due to the fact that there is no basic information for analysis or studies; that allows the producer to have livestock feeding planning systems and to be able to predict their growth taking into account climatic conditions [14], which would allow calculating losses or gains if their influence is demonstrated. Having these elements of judgment for decision-making, it allows to plan the adequate diet of cattle in search of increasing productivity so that beef is competitive in the region. By virtue of this, different measurements have been collected, and based on these observations, all the variables that have been considered relevant have been constructed to evaluate which of them and how much they vary the weight gain of cattle. It is intended that both this and other similar investigations be the cornerstone for livestock producers to be able to use their own resources, such as land use, pasture crops, complementary foods, and information derived from climatic conditions, with a primary focus on sustainable and competitive meat production.

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METHODOLOGY

For the development of the study, the research is of a descriptive correlational type because a correlative analysis is broken down between the independent variables with respect to the dependent variable, it also had a non-experimental field design since the samples were taken directly in the studied space, where the variables were not manipulated at all. To calculate the statistics, a linear regression analysis was developed with the intention of predicting the behavior of the dependent variable with respect to the data obtained from the independent ones. In principle, there were weight measurements in kilograms (kg) for a sample of forty cattle specimens, all of them corresponding to the weight of the animal every fortnight of the month. Based on this, with the observations obtained directly from the field by using measurement instruments corresponding to each variable (precipitation, forage height, protein percent, temperature, and humidity), the independent variables were calculated and defined (see Table 1).

As a first step to predict the behavior of cattle weight gain under the influence of the other variables included in the study, it was necessary to select the independent variables to be included in the linear regression analysis. To do this, the Spearman (R) linear correlation coefficient of the dependent variable was calculated with respect to each of the independent variables included.

Once the regression analysis was carried out using the StatGraphics program, the result was a multiple linear regression model defined by the equation $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + ... + \beta_nX_n + e_i$ where Y was the dependent variable, X_n was each one of the independent variables selected for the model, β_n was each one of the coefficients corresponding to each independent variable included in the model, and β_0 was the intercept of the model, that is, the value of the dependent variable Y when all its predictors are zero (0). For each model obtained, the significance (P-value) of each of the regression coefficients (β_n) estimated for each variable would be calculated with a confidence level of 95%, that is, a significance level (α) of 0.05. Finally, by means of a residual analysis, the principle of non-autocorrelation was verified, an indispensable condition to validate the linear regression between two or more variables [15].

Using the StatGraphics software, the "Observed Y vs. Predicted Y" graph was obtained to evaluate the dispersion between the observed and predicted values of the dependent variable. With the same software, the residuals were plotted according to their order of appearance to verify that they did not follow a variation pattern and thus corroborate the principle of non-autocorrelation, which was verified by calculating the Durbin-Watson statistic and its respective P- value.

RESULTS AND DISCUSSION

For a confidence level of 95%, the Spearman (R) correlation coefficient of the dependent variable studied with each of the proposed independent variables was calculated with StatGraphics, where:

Y: Average weight gain of cattle (kg).
X_9: Accumulated precipitation (mm).
X_8: Average daily precipitation (mm).
X_7: Height of average daily forage consumed (cm).
X_6: Mean daily percentage of forage consumed (%).
X_5: Average protein percentage of the consumed forage (%).
X_4: Registered average daily thermal variation (°C).
X_3: Maximum average temperature recorded (°C).
X_2: Minimum average temperature recorded (°C).
X_1: Average relative humidity recorded (%).

As a result, a correlation table was obtained (see Table 2). Given the results obtained, for a confidence level of 95% ($\alpha = 0.05$) the following can be stated:

1. Only the variables X_9, X_8, X_2, and X_1 have a truly significant correlation with the dependent variable studied, since their P-values are lower than the significance level used in the study ($\alpha = 0.05$).
2. The independent variables X_9 (R = 0.6636), X_8 (R = 0.6491) and X_1 (R = 0.5335) present a moderate positive correlation with the dependent variable studied ($0.5 < R < 0.7$).
3. The independent variable X_2 (R = -0.5255) presents a moderate negative correlation with the studied dependent variable ($-0.7 < R < -0.5$).

Finally, by virtue of the previously described criteria, the independent variables X_9, X_8, X_2, and X_1 were selected for the multiple linear regression analysis. In this way, the multiple linear regression model (A) was built, defined by the following equation:

(A) $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_8 X_8 + \beta_9 X_9$

Where:
Y: Cattle average weight gain (kg)

X_1: Recorded average ambient humidity (%)
X_2: Average minimum temperature recorded each day (°C)
X_8: Average daily precipitation (mm)
X_9: Accumulated precipitation at the end of the month (mm)
β_0: Regression coefficient for the intercept with the Y axis. It corresponds to the minimum expected value of the dependent variable Y when the value of all the independent variables (X_1, X_2, X_8, X_9) is equal to zero (0)
β_1: Partial regression coefficient for the independent variable X_1
β_2: Partial regression coefficient for the independent variable X_2
β_8: Partial regression coefficient for the independent variable X_8
β_9: Partial regression coefficient for the independent variable X_9

As a first step in the construction of the model, an analysis of variance (ANOVA) was carried out using the F-Snedecor test, which is used in multiple regression models to determine if at least some of the predictors introduced in the model contributes significantly [16]. This test considers the null hypothesis that all the estimated correlation coefficients are zero, against the alternative hypothesis that at least one of them is not.

Performed the test by means of StatGraphics, for $\alpha = 0.05$ it is obtained what is shown in Table 3.

Since the P-value is less than the significance level used in the model (P-Value = $0.0000 < \alpha = 0.05$), the null hypothesis is rejected (H_0). There is sufficient evidence to affirm that at least one of the independent variables (X_1, X_2, X_8, X_9) has some level of correlation with the dependent variable studied (Y).
Subsequently, the partial regression coefficients were calculated for each of the variables included in the model (β_0, β_1, β_2, β_8, β_9), evaluating each of them using the T-Student test, whose P-value would determine if the variable in question contributed significantly to the model. The data were entered into Statgraphics, obtaining the regression coefficients (see Table 4).

It is found that all the calculated P-values turned out to be less than $\alpha = 0.05$. Therefore, for all the independent variables included in the multiple linear regression model (A), H_0 is rejected. This means that there is sufficient evidence to affirm that the changes in cattle weight gain (Y) are linearly related to the accumulated precipitation (X_9), the average daily precipitation (X_8), the average minimum temperature (X_2) and the average relative humidity (X_1).

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Likewise, given β_0 = 23.4926, β_1 = 0.0383579, β_2 = -0.852, β_8 = -1.63473, β_9 = 0.108424, the multiple linear regression model [2] is expressed as follows:

(A) $Y = 23.4926 + 0.0383579X_1 - 0.852X_2 - 1.63473X_8 + 0.108424X_9$

Once the multiple linear regression model has been expressed, the coefficient of determination (R^2) is calculated and interpreted as the amount of variance of the dependent variable explained by the independent variables evaluated. For the multiple linear regression model (A), the StatGraphics package returned what is shown in Table 5.

In the same way, the Observed Y Vs. Predicted Y scatter plot was generated, which represents the R2 as the visible fit of the predicted data with respect to the observed data for the dependent variable studied.

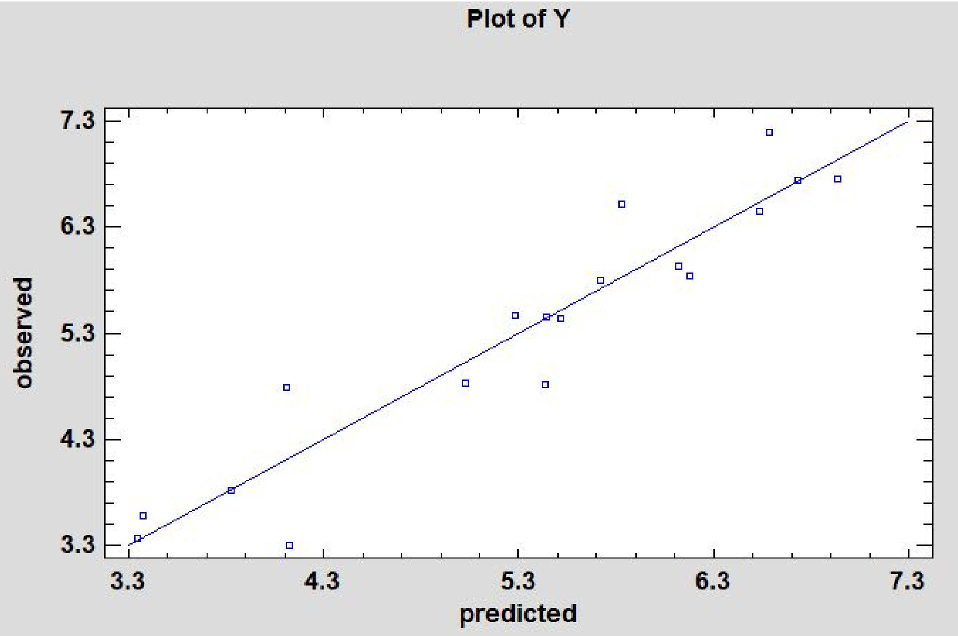

Figure 1: Observed Y Vs. Predicted Y for model of multiple linear regression (A)

Finally, for the multiple linear regression model (A), the residual analysis was carried out, whose first step was the calculation of each one of the residuals derived from the prediction of Y values for the multiple linear regression model (A), obtaining the predicted values (see Table 6).

Using Statgraphics, the Durbin-Watson (DW) statistic was calculated. For the multiple linear regression model (A), being α = 0.05, it was obtained:

DW Statistic = 1.7889

P-value$_{DW}$ = 0.1561 > 0.05 ⇒ H_0 is not rejected

There is not enough evidence to affirm that there is a significant autocorrelation between the residuals, which can be seen in the residuals graph shown below:

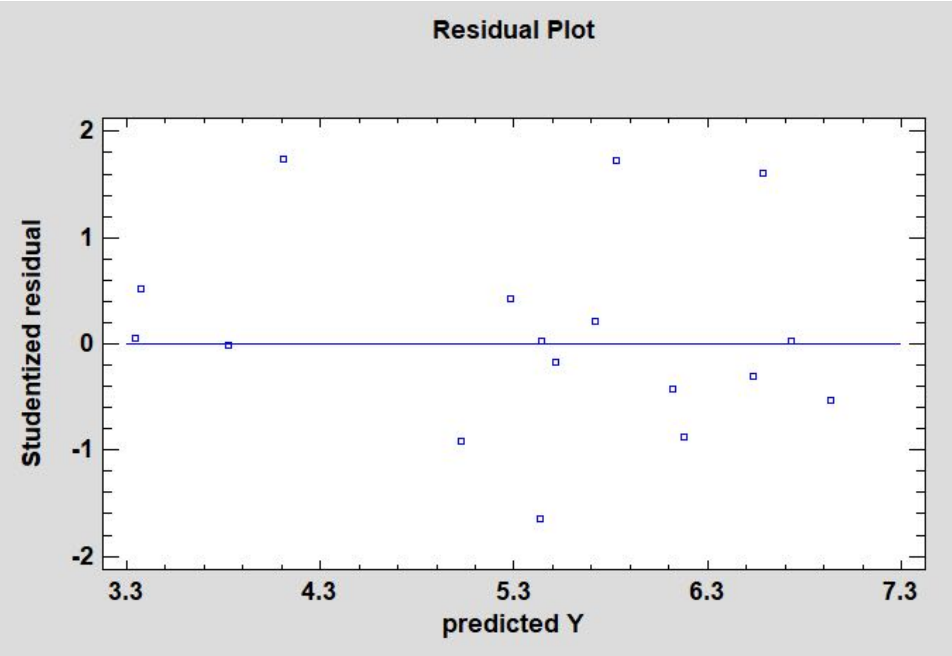

Figure 2: Residual plot for model of multiple linear regression (A)

As can be seen in Figure 2, the residuals do not show a non-random pattern of variation, which is verified with the P-value obtained for the Durbin-Watson statistic, whose result has been higher than the significance level used in the study (α = 0.05). It is then corroborated that the multiple linear regression model (A) is valid to explain the behavior of the dependent variable studied with respect to the independent variables included in the model.

Because it was determined that the only independent variables that have a significant correlation with the behavior of the dependent variable studied are accumulated precipitation (X_9), average daily precipitation (X_8), average daily minimum temperature (X_2), and humidity average daily relative (X_1), these were the only ones finally included in the multiple linear regression model (A).

By virtue of the results obtained for the P-value of the regression coefficients (β_0, β_1, β_2, β_8, β_9), it is plausible to affirm, with a confidence level of 95% (α = 0.05), that the model of Multiple linear regression (A) is the most appropriate model to predict

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the behavior of the average weight gain of monthly cattle (Y) under the effect of the meteorological and nutritional variables included in the present study. Since all the P-values of the model coefficients are less than the significance level ($\alpha = 0.05$), it can be concluded that it is not necessary to remove any of the independent variables from the model.

On the other hand, for the constructed linear regression model, the coefficient of determination $R^2 = 89.3691\%$ was obtained, that is, for the significance level $\alpha = 0.05$ (95% confidence level), it can be affirmed that the model of Multiple linear regression (A) explains the behavior of the average monthly cattle weight gain by 89.3691%. This, however, does not imply that there is a causal relationship between the independent variables included in the final model and the dependent variable [17], but it does indicate that there is a statistical effect of precipitation, relative humidity, and environmental temperature on cattle weight gain.

Synthesizing the findings achieved in the statistical analysis developed in the present work, it can also be affirmed that up to now there is no statistical evidence that the nutritional variables (height of grass consumed, percentage of grass consumed, percentage of protein in the grass) exert any significant influence on the weight increase of the studied cattle population, but not with the meteorological variables, of which evidence was found that at least four of them (X_1, X_2, X_8, X_9) do significantly explain cattle weight gain. The results obtained at the end of the present investigation corroborated the reviews of other researchers regarding the effect of changes in climatic conditions on the growth of cattle [18]. There is clear evidence that forage conditions greatly affect the weight gain of cattle [19]. However, it is plausible to state that the data collected for forage heights and protein percentage were not, for now, sufficiently decisive for the analysis to confirm these assumptions [20].

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

It is important to consider that the statistical model implemented in the present study does not apply to all existing cattle populations but only emerged in the specific location with the specific behavior observed in the independent variables studied. Its contribution mainly comes to be to record that adequate statistical models can be built for each bovine population to predict their behavior, either of the variable of weight gain in kilograms or any other that is desired to be subjected to study. In other words, to predict the weight gain of a different population of cattle with other climatic or nutritional conditions, another simple or multiple linear regression model must be built from scratch, as appropriate.

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It is recommended for future work to have a larger amount of observed data to have greater reliability both in the behavior of the data and in the traceability of the statistical model, which should be clear that it is not the purpose but the main tool used in this work, whose fundamental contribution is to provide information to livestock producers on the changes in the productive performance of cattle associated with climatic conditions (non-manipulable) and nutritional conditions (manipulable) to which it is exposed.

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Table 1: Biweekly calculations obtained from the observed data from every variable included in the study

Period	Average cattle weight gain (kg)	Accumulated precipitation (mm)	Daily average precipitation (mm/dia)	Forage height consumed (cm)	Percentage of fodder consumed (%)	Protein in forage (%)	Average Thermal Variation (°C)	Average maximum temperature (°C)	Average minimum temperature (°C)	Average relative humidity (%)
31Jan - 14Feb	3.31	2	0.13	69.64	42.17	13.00	31.00	24.07	6.93	29.50
15Feb - 28Feb	3.37	5.5	0.39	77.86	52.78	13.14	31.21	24.50	6.71	20.07
01Mar - 15Mar	3.58	17.5	1.17	95.33	62.96	13.00	31.73	25.00	6.73	31.13
16Mar - 31Mar	3.82	14	0.88	79.00	46.39	13.00	32.00	25.00	7.00	40.44
01Apr - 15Apr	4.79	26	1.73	75.00	68.33	13.00	32.00	25.13	6.87	53.07
16Apr - 30Apr	4.83	213	14.20	110.00	61.84	13.50	31.80	25.00	6.80	77.07
01May - 15May	4.81	24.5	1.63	87.50	50.83	13.00	31.40	25.13	6.27	87.60
16May - 31May	5.80	9	0.56	65.00	39.67	13.67	31.06	25.06	6.00	91.63
01Jun - 15Jun	5.44	57	3.80	125.00	72.81	12.50	31.47	25.00	6.47	87.40
16Jun - 30Jun	5.45	35	2.33	85.00	44.72	13.50	31.60	25.00	6.60	85.00
01Jul - 15Jul	5.47	77.5	5.17	60.00	57.73	13.00	31.82	25.00	6.82	81.82
16Jul - 31Jul	5.84	101.5	6.34	80.00	43.53	13.00	31.19	25.00	6.19	87.13
01Aug - 15Aug	5.93	96.5	6.43	70.00	47.32	13.00	31.07	24.33	6.73	88.67
16Aug - 31Aug	6.45	173	10.81	77.50	44.17	13.50	32.06	24.25	7.81	68.13
01Sep - 15Sep	6.51	74.5	4.97	100.00	73.86	12.00	32.20	24.13	8.07	76.60
16Sep - 30Sep	6.74	106	7.07	105.00	54.34	13.00	31.00	23.73	7.27	91.73
01Oct - 15Oct	6.75	52.5	3.50	80.00	42.22	13.00	29.80	23.13	6.67	82.80
16Oct - 31Oct	7.19	82.5	5.16	95.00	70.60	13.00	30.89	23.89	7.00	76.56

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Table 2: Spearman rank correlations between the dependent variable and each one of the studied independent variables

Correlation	X_9	X_8	X_7	X_6	X_5	X_4	X_3	X_2	X_1
Average cattle weight gain (Y)	0.66	0.65	0.17	0.03	-0.11	0.19	-0.27	-0.53	0.53
P-value	0.01	0.01	0.47	0.90	0.65	0.43	0.26	0.03	0.03

Table 3: Analysis of Variance for the Model of Multiple Linear Regression (A)

Source	Df	Sum of squares	Mean Square	F-Ratio	P-Value
Regression	4	22.41	5.60	27.32	0.0000
Residual	13	2.67	0.21		
Total (Corr.)	17	25.07			

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Table 4: Obtained coefficient from the model of multiple linear regression (A)

Parameter	Estimate	Standard Error	T Statistic	P-value
CONSTANT	23.49	4.62	5.08	**0.00**
X_9	0.11	0.04	2.67	**0.02**
X_8	-1.64	0.63	-2.61	**0.02**
X_2	-0.85	0.17	-4.56	**0.00**
X_1	0.04	0.01	7.47	**0.0000**

Table 5: R^2 and adjusted R^2 obtained for model of multiple linear regression (A)

R Square	Standard Error	Mean absolute error	Observations	Adjusted R Square
89.37%	0.45	0.28	18	86.10%

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Table 6: Predicted values and residuals of model of multiple linear regression (A)

Observation	Observed values for Y	Predicted values for Y according to model of linear regression (A)	Residuals (Observed Y - Predicted Y)
1	3.31	4.12	-0.82
2	3.37	3.34	0.04
3	3.58	3.37	0.20
4	3.82	3.83	-0.01
5	4.79	4.10	0.69
6	4.83	5.02	-0.20
7	4.81	5.43	-0.62
8	5.80	5.72	0.09
9	5.44	5.51	-0.07
10	5.45	5.44	0.01
11	5.47	5.29	0.18
12	5.84	6.17	-0.34
13	5.93	6.11	-0.18
14	6.45	6.53	-0.08
15	6.51	5.83	0.68
16	6.74	6.73	0.01
17	6.75	6.93	-0.17
18	7.19	6.59	0.59

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