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STATISTICS

Evaluation of the behavior of thrips in several ground covers by regression models

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ABSTRACT. Using the number of thrips found in the maize seedlings from a longitudinal study, in this work a regression analysis was conducted through polynomial models and nonlinear logistic, under the assumption of homoscedasticity and multiplicative heteroscedasticity of variances. The response variable represents the number of thrips in adult phase observed in an entirely randomized trial involving 4 ground cover systems (tumbled oat, desiccated oat, mowed oat and incorporated oat), 8 replications with portions of 57.6 m^2 and evaluated at 7, 11, 16, 23 and 31 days after the seedlings emergence. The parameters from the adopted models (homoscedastic and heteroscedastic) were estimated by maximizing the logarithm of the verisimilitude function. The adjusted model, via maximum verisimilitude, under the assumption of heteroscedasticity of the variances, did not over estimate the true asymptotic average number of thrips.

Keywords: ground cover, nonlinear regression, heteroscedastic errors.

Avaliação do comportamento de tripes em coberturas de solo via modelos de regressão

RESUMO. Utilizando o número de tripes encontrados nas plântulas de milho, proveniente de um estudo longitudinal, neste artigo é conduzida uma análise de regressão por meio de modelos polinomiais e não linear logístico, sob as suposições de homocedasticidade e heterocedasticidade multiplicativa das variâncias. A variável resposta representa o número de tripes, na fase adulta, observados em um ensaio inteiramente aleatorizado, envolvendo 4 sistemas de cobertura do solo (aveia tombada, aveia dessecada, aveia roçada e aveia incorporada), 8 repetições com parcelas de 57,6 m^2 e avaliadas aos 7, 11, 16, 23 e 31 dias após a emergência das plântulas. As estimativas dos parâmetros dos modelos adotados (homocedástico e heterocedástico) são obtidas maximizando-se o logaritmo da função de verossimilhança. O modelo ajustado via máxima verossimilhança, sob a suposição de heterocedasticidade de variâncias não superestima o verdadeiro número médio assintótico de tripes.

Palavras-chave: cobertura de solo, regressão não linear, erros heterocedásticos.

Introduction

Maize, a grain which is essential to food for both, human and animal populations, is constantly the target of researches. Several researches were developed and/or have been developed in order to minimize the soil abrasion, and consequently, obtain production. Among them, it is highlighted the no-tillage system Oliveira, Novaes, Alvarez, Cantarutti, and Barros (2002), Wietholter, Bem, Kochhann, and Pottker (1998), and those that use some kind of ground covers among others (Streck, Schneider, & Buriol, 1994; Cerreta, Novaes, Alvarez, Cantarutti, & Barros, 2002).

Khatounian (2008) found a strong correlation between the increase in oat straw and the lower incidence of invasive plants, which results in both, a lower cost and the facility to control such invasive plants. Carvalho, Silva, Pissaia, Pauletti, and Possamai (2007) evaluated the effect of winter cover species and found that the cover made with black oat and forage turnip provided a higher productivity of maize grains than the coverage with single vetches. Caires, Garbuio, Alleoni, and Cambri (2006) found that the use of ground cover with black oat increased the concentrations of phosphorus, calcium and magnesium in maize leaves and that maintaining the oat residue on the soil surface contributed to the grain yield.

According to Albuquerque, Crocomo, and Scapim (2006), in some maize farming located in different municipalities of the states of Paraná, Santa Catarina and Minas Gerais, in addition to traditional pests that cause damage, a high emergence of thrips populations have been observed. The attack is more intensively evident in the first weeks after the emergence of growing seedlings in water deficit conditions, and they embrace a large range of habitats, especially in tropical regions (Carvalho et al., 2007). In addition to the direct damage caused by feeding, the presence of thrips on plants can also often lead to their death (Albuquerque et al., 2006). Damage caused by thrips can result in a significant production loss, also affecting the quality of the product and, thus, its commercialization (Carvalho et al., 2007).

In certain practical situations, the relationship between the dependent and independent variables can be observed by means of a regression analysis. The regression analysis either with a linear or nonlinear model is a potentially useful technique in data analysis, having a great applicability in several areas of knowledge, such as Biology, Zoology, Agronomy, Forest Engineering, among others. The linear regression is widely used for representing biological phenomena, such as the growth of living organisms in its initial phase. However, these phenomena when studied over a given time are not well represented by a linear function, making it necessary an adjustment of non-linear functions that best explain the process (Draper & Smith, 1981; Ratkowsky,1983).

A nonlinear model is chosen based on the theoretical foundation of an expert in the area. Therefore, specific knowledge of Biology, Physics, Chemistry, Ecology or Zoology may automatically lead to a model for the response function, the so-called mechanistic models. Among the nonlinear models, perhaps the best known and used one is the class of growth models. These models describe the growth with changes of the regression variable. For example, a nonlinear regression model can write the increase of the number of thrips found in a plant, after the seedlings emergence, related to time.

When fitting either a linear or nonlinear regression model, considering the data observed over time, where y_{ij} denotes the i^{th} response observed at j occasion, it is common to assume that the errors of the adopted model are uncorrelated and that their variances are constant in all j (Montgomery, Peck, & Vining, 2001). This assumption is known in the literature as the homoscedasticity of the variances. When confirming the breakdown of the homogeneity assumption of the variances, that is, the presence of heteroscedasticity, the inferences, confidence intervals and hypothesis testing may yield inaccurate results (Deaton, Reynolds, & Myers, 1983).

In situations that accentuate the presence of heteroscedasticity, the literature suggests that some appropriate changes of the response variable is searched, and/or covariate, in order to stabilize the variances, Box and Cox (1964), Atkinson (1985). Thus, it is desired to adjust nonlinear models with homoscedastic and heteroscedastic errors in order to evaluate each ground cover system, taking the number of thrips as response.

Material and methods

The data used are part of several experiments carried out by the Department of Agronomy, the State University of Maringa (UEM) in the experimental areas installed at the Experimental Farm of Iguatemi (FEI) of UEM. The study was performed in Dystrophic Red Yellow Argisol (Ultissol), where the hybrid known as Exceler was used in order to verify the behavior of the thrips.

The essay was conducted in a completely randomized design, with four different systems of ground covers in eight replications with plots of 57.6 m^2. The plants were evaluated in five different periods. The cover systems were used in areas grown with oat, as it follows: Ground Cover System with tumbled oat, GCS1: oat previously desiccated with glyphosate, rolled with open grill, and then, maize sowing was carried out; Ground Cover System with desiccated oat, GCS2: maize sowing directly on the desiccated oat; Ground System with mowed oat, GCS3: oat dried and mowed to subsequently undertake maize sowing; Ground Cover System with incorporated oat, GCS4: oat incorporated through conventional harrowing and sowing.

In all ground cover systems, sowing was carried out on 23rd October, 2003. All the operations of cutting, mowing, incorporating with a grid, and desiccating oats with glyphosate herbicide occurred 17 days prior to the maize sowing. At the time of those operations, the oats were in the final flowering stage and approximately 70 cm tall.

After the emergence of maize seedlings, the selected plants were cut close to the ground, placed in plastic bags and taken to the laboratory, where they remained in refrigerator for at least 30 min at a temperature of 6°C in order to reduce the movement of the thrips and prevent them to let the plants during the extraction process. The extraction of thrips was carried out by washing them with 70% ethanol and filtering with a fine fabric mesh. Subsequently, with the support of a stereoscopic microscope, the species of thrips named *Frankliniella Williamsi* were separated and counted according to the classification of adults and nymphs. When counting the nymphs, the nymph al stages were not differentiated. This procedure was repeated at 7, 11, 16, 23 and 31 days after seedling emergence (evaluation period). The evaluations were always carried out in the morning, between 8 and 9 o'clock.

According to Draper and Smith (1981) nonlinear models have wide application in Biology, Zoology, Ecology and Forest Engineering, with which it is possible to model the growth of plants, trees, animals and human beings .

In Agronomy, Biology, Ecology and Engineering there are often phenomena producing sigmoidal curves in the form of S. Such curves begin at a fixed point and grow monotonically up to an inflection point; thereafter the growth rate begins to decrease until the curve approaches a final value, which is called asymptote value. Among the sigmoidal model the following ones must be highlighted: Gompertz, Logistic, Richards, Morgan-Mercer-Flodin and Weibull (Ratkowsky, 1983; Gonçalves et al., 2011; Mansano, Stefani, Pereira, & Macente, 2012).

The relationship variable between the response/independent variable of the nonlinear models can be represented by the following Equation 1:

$$y = f(x;\theta) + \varepsilon \qquad (1)$$

where:
$y = (y_1, y_2, \ldots, y_n)'$ and $x = (x_1, x_2, \ldots, x_n)'$ are the vectors of the response and explanatory variables, respectively, and $\theta = (\theta_1, \theta_2, \ldots, \theta_p)'$ is the vector of unknown parameters, $f(x;\theta) = (f(x_1;\theta), f(x_2;\theta), \ldots, f(x_n;\theta))$ is a function of both, the regressive variables and the parameters, which is named as either mean function or regression function and $\varepsilon = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p)'$ is the vector of random errors. In general, due to inference reasons, it is assumed that the errors are independent and identically distributed normal random variables with a zero-mean and constant variance $\sigma^2 I_n$, where I_n is the identity matrix of n order (homoscedasticity of the variances). Under the assumption of heteroscedasticity of the variances, it is considered that $\varepsilon_{ij} \sim N(0, \sigma_i^2)$ where $\sigma_i^2 = \sigma_i^2 x_j^{\lambda}$ is the parameter that characterizes the variance of the response variable in the j^{th} explanatory variable. For $\lambda = 0$, we have the homoscedastic model as particular case (for more details see Mazucheli, Souza, & Philippsen, 2011).

Regarding the parameter estimation methods, there are several numerical procedures. A method widely used in nonlinear regression is Gauss-Newton's iterative ones, which is based on Taylor's first-order series approximation to produce a linearization of the nonlinear function, and, then, apply the theory of least squares to obtain new estimates of the parameters that tend to minimize the sum of square errors.

Considering the data described, y_{ij} is the number of thrips observed (the response variable) of the i^{th} plant in the j^{th} evaluation period (the independent variable), and the real functional relationship y_{ij} versus x_j is accordingly described by the non-linear regression models in relation to the type of ground cover used.

For the ground GCS1: cover system with tumbled oat the adopted model was Equation 2:

$$y_{ij} = \alpha + \beta x_j + \theta x_j^2 + \varphi x_j^{-1} \qquad (2)$$

where:
i = 1, ..., 40;
j = 1, 2, 3, 4, 5,
where:
$x_1 = 7$, $x_2 = 11$, $x_3 = 16$, $x_4 = 23$ and $x_5 = 31$ and $(\alpha, \beta, \theta, \varphi)$ are the parameters vector.

For the ground GCS2 and GCS3 cover systems with both, desiccated oat and mowed oat the adopted model was Equation 3:

$$y_{ij} = \frac{\alpha}{1 + \exp\{-(\beta + \theta x_j)\}} \qquad (3)$$

where:
i = 1, ..., 40;
j = 1, 2, 3, 4, 5,
where:
$x_1 = 7$, $x_2 = 11$, $x_3 = 16$, $x_4 = 23$ and $x_5 = 31$ and (α, β, θ) are the parameters vector.

For ground GCS4: cover systems with incorporated oat the adopted model was Equation 4:

$$y_{ij} = \alpha + \beta x_j + \theta x_j^2 + \varphi x_j^3 \qquad (4)$$

where:
i = 1, ..., 40;
j = 1, 2, 3, 4, 5,
where:
$x_1 = 7$, $x_2 = 11$, $x_3 = 16$, $x_4 = 23$ and $x_5 = 31$ and $(\alpha, \beta, \theta, \varphi)$ are the parameters vector.

It is important to point out that for GCS2 and GCS3 were fitted the sigmoidal logistic model, where α is the maximum expected value for the response variable (number of thrips), β is related to the intercept, that is, value of to $E(y)$ when $x = 0$ and θ is related to the mean rate of the curve growth.

Considering the functional forms of the models for each ground cover system there is the verisimilitude function. By applying the logarithm function, deriving it in relation to the parameters, and equating it to zero, a nonlinear equation system is obtained, which must be solved by an iterative method. In this paper, the SAS/NLMIXED procedure was used for the maximization of the log-verisimilitude function (Littell et al., 1996). Some suggestions shown in Ratkowsky (1983) were used in order to obtain the initial values of the parameters in the iterative procedure.

Results and discussion

In practical situations, where the response variable is the count of the number of thrips over time, the homoscedasticity assumption may not be reasonable (Mazucheli et al., 2011). As a factual example, the data from the longitudinal study must be considered, in which plants were evaluated at 7, 11, 16, 23 and 31 days after seedling emergence in four cover ground systems with oat. This planned experiment was carried out at FEI, UEM, in order to estimate the average number of thrips in the different ground cover systems (GCS) (Albuquerque et al., 2006).

Figure 1 shows, for each ground cover system, the behavior of the number of thrips over the five assessments, whereas Table 1 shows the means and standard deviations of the numbers of thrips, in each evaluation period as well. Considering all GCSs, it is observed that the average number of thrips increase as days pass by, as it was expected. The percentages of changes in the quantities of thrips during the subjacent days for each cover system, that is, GCS1, GCS2, GCS3, GCS4, were the following: from 7 to 11 days: 163.64, 566.67, 133.33 and 72.73%; from 11 to 16 days: 20.69, 331.25, 76.19 and -15.79%;, from 16 to 23 days: 4.29, 73.92, 264.86 and 1.56%; from 23 to 31 days: 127.39, 96.67; 44.44 and 79.49%. Regarding the standard deviations for GCS1, GCS2 and GCS3, they increase until the 16 day of evaluation, then, they decrease until the 23 day of evaluation, and, then, they decrease once more. GCS4 decreases until the evaluation at 23 day, and, then, it increases once more (Table 1).

Figure 1 shows a non-linear behavior for the number of mature thrips, as well as non-constant variances, a fact that highlights the collapse of the usual homoscedasticity assumption. For all types of ground covers, Bartlett's test rejected the homogeneity hypothesis of the variances ($p < 0.0001$). Therefore, inferences, confidence intervals and hypothesis test, might produce inaccurate results, especially when the sample size is small, Deaton et al. (1983).

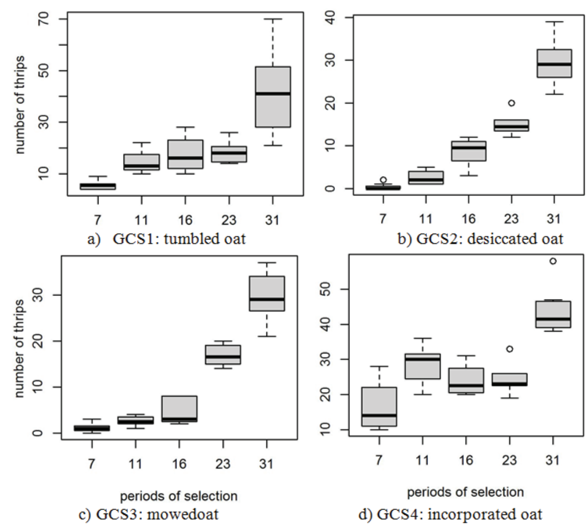

Figure 1. Box-plot of the behavior of the number of mature thrips for each ground cover system in the different periods of selection.

Table 1. Mean and variance of the number of mature thrips according to ground cover systems and the evaluation periods.

Evaluation periods	Ground cover systems	Mean	Variance
7	GCS1: tumbled oat	5.500	2.857
	GCS2: desiccated oat	0.375	0.554
	GCS3: mowed oat	1.125	0.982
	GCS4: incorporated oat	16.500	49.714
11	GCS1: tumbled oat	14.500	17.429
	GCS2: desiccated oat	2.500	2.857
	GCS3: mowed oat	2.625	1.125
	GCS4: incorporated oat	28.500	32.040
16	GCS1: tumbled oat	17.500	42.246
	GCS2: desiccated oat	8.625	9.982
	GCS3: mowed oat	4.625	8.011
	GCS4: incorporated oat	24.000	17.724
23	GCS1: tumbled oat	18.250	17.357
	GCS2: desiccated oat	15.000	6.000
	GCS3: mowed oat	16.875	4.978
	GCS4: incorporated oat	24.375	17.135
31	GCS1: tumbled oat	41.500	269.942
	GCS2: desiccated oat	29.500	28.302
	GCS3: mowed oat	29.625	26.839
	GCS4: incorporated oat	43.750	43.963

For stabilizing the variances in the presence of heteroscedasticity, in general the literature suggests the search for an appropriate change for any response variable, Box and Cox (1964), Atkinson (1985), and Russell and Bobko (1990).

Harvey (1976), when analyzing non-homogeneous variance data, considers the adjustment of the nonlinear regression models where the variance is the multiplicative function of the levels of the evaluation period covariate. This proposal is based on the evidences of the findings shown in Table 1.

Considering the adjustment of the nonlinear models heteroscedastic to systems GCS1 and GCS4 the model is a polynomial (1) and (3) respectively, for GCS2 and GCS3 the non-linear model is logistic (2).

Regarding the number of mature thrips, in four ground cover systems, Table 2, 3, 4 and 5 show the estimates of maximum verisimilitude and the asymptotic standard errors of the vector of the parameters $\psi = (\alpha, \beta, \theta, \varphi, \sigma, \lambda)$ for all the ground cover systems.

Table 2. Maximum verisimilitude estimates (standard errors) for the ground GCS1: tumbled oat, model 1.

Models	α	β	θ	φ	σ	λ
Homoscedastic	144.570	-8.853	0.198	-609.717	7.911	
	(47.957)	(3.094)	(0.058)	(213.675)	(0.884)	
Heteroscedastic	123.493	-7.459	0.172	-519.49	6.321	0.182
	(36.324)	(2.576)	(0.0524)	(147.464)	(1.048)	(0.014)

Table 3. Maximum verisimilitude estimates (standard errors) for the ground GCS2: desiccated oat, model 2.

Models	α	β	θ	φ	λ
Homoscedastic	43.812	-4.291	0.1614	3.114	
	(9.811)	(0.326)	(0.028)	(0.348)	
Heteroscedastic	33.496	-5.119	0.224	2.658	0.198
	(4.207)	(0.422)	(0.029)	(0.604)	(0.030)

Table 4. Maximum verisimilitude estimates (standard errors) for the ground GCS3: mowed oat, model 2.

Models	α	β	θ	φ	λ
Homoscedastic	34.605	23.310	4.288	2.754	
	(3.052)	(1.120)	(0.667)	(0.307)	
Heteroscedastic	36.914	24.133	4.801	1.967	0.221
	(4.022)	(1.441)	(0.512)	(0.393)	(0.034)

Table 5. Maximum verisimilitude estimates (standard errors) for the ground GCS4: incorporated oat, model 3.

Models	α	β	θ	φ	σ	λ
Homoscedastic	-31.335	10.917	-0.651	0.012	5.547	
	(12.282)	(2.445)	(0.142)	(0.002)	(0.620)	
Heteroscedastic	-29.751	10.598	-0.633	0.012	1.967	-0.248
	(12.982)	(2.542)	(0.146)	(0.003)	(0.393)	(0.0392)

The verisimilitude ratio test shows the hypothesis that $\lambda = 0$ is rejected, which high lights that the heteroscedastic model is more appropriate than the homoscedastic one. This fact is expected, since in longitudinal situations in general it is not reasonable to assume homoscedasticity.

Table 6 shows the sum of squared residuals considering the adjustment of homoscedastic and heteroscedastic models.

Table 6. Sum of the squares of the residuals of the adjusted models and p-values.

Ground cover systems	Homoscedastic	Heteroscedastic	P-value
GCS1: tumbled oat, model 1	2516.065	2503.226	< 0.001
GCS2: desiccated oat, model 2	423.179	387.398	< 0.001
GCS3: mowed oat, model 2	308.351	303.446	< 0.001
GCS4: incorporated oat, model 3	1230.714	1203.175	< 0.001

Observing the values, there are evidences that the nonlinear heteroscedastic models are better suited to the data in question.

Figure 2 shows the models adjusted for the different ground cover systems in all periods of the evaluation of the plants. The adjusted models captured well the distribution of the data observed in each ground cover system.

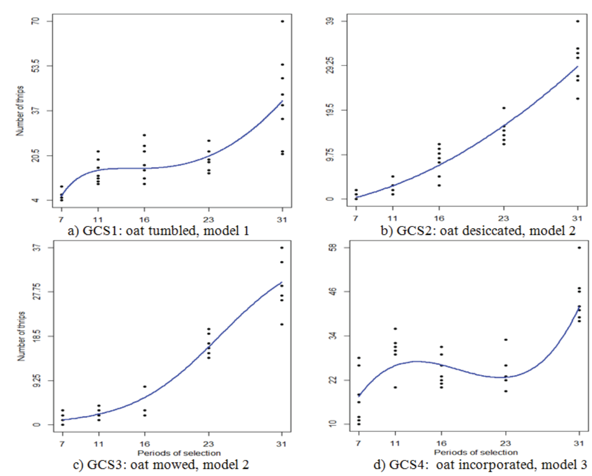

Figure 2. Heteroscedastic models adjusted for each ground cover system depending on the different periods of selection.

The different ground cover systems significantly influenced the infestation of maize by thrips, and the cover systems with desiccated and mowed oat had a lower incidence of thrips throughout the study period, Figure 3.

If it is considered that 10 thrips plant^{-1} are the limit for performing intervention with insecticide, soil covers with desiccated oat (GCS2) and mowed oat (GCS3) are substantially better, and do not require intervention as they present a number of thrips significantly lower when compared to the other cover systems. Moreover, soil cover performed with incorporated oat (GCS4) should first receive intervention with insecticide for presenting the higher number of thrips in adult phase.

It is noteworthy that at the time of the 23 days evaluation, after the seedlings emergence, the soil cover systems with desiccated oat (GCS2) and mowed oat (GCS3) had a substantial increase in the average number of thrips. However, when considering the whole evaluated period, these cover systems presented the lowest incidence of thrips in adult phase.

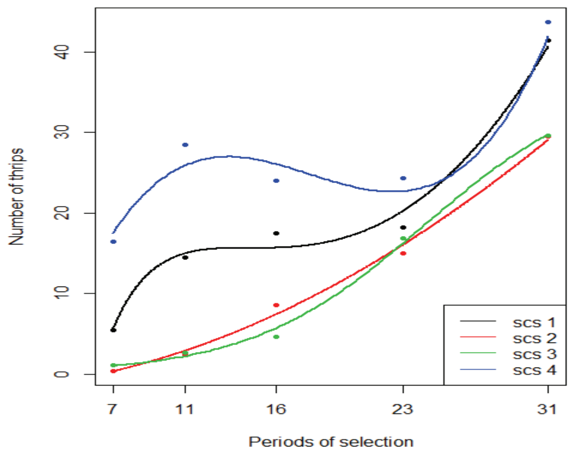

Figure 3. Comparison of heteroscedastic models adjusted for each ground cover system.

In GCS2, the maize seedling occurs direct after oat desiccation, whereas in GCS3 the oat are desiccated and, then, mowed. Therefore, the mowed stage is the difference between both cover systems. Taking into account that both covers are effective to decrease the incidence of thrips in adult phase [the values of the asymptotes for GCS2 (33,496) and GCS3 (36,914)] and each cover system estimates, the use of GCS2, besides decreasing the incidence of thrips, will also cause a significant work reduction for the farmer by not having to do the mowed before maize planting.

Conclusion

The nonlinear heteroscedastic models allowed the visualization of the number of thrips distribution over time.

The different soil cover systems had significant influence over the infestation of thrips in the maize plants, being the cover systems with desiccated oat and mowed oat the ones that presented the lowest incidence of thrips over the evaluated period, these results being confirmed by Albuquerque, Crocomo and Scapim in 2006.

The recommendation for the farmer who adopts with the no-till system for maize growing is the adoption of the soil cover system with desiccated oat, which constitutes a good measure in controlling thrips and requires less work.

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